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The Allan Hills, southern Victoria Land. At the 13th Antarctic Treaty meeting in Brussels, Belgium, representatives of the 32 Antarctic Treaty Consultative Parties made 16 recommendations to their governments; 11 of these focused on the preservation of Antarctica's environment. This issue of the Antarctic Journal reports on this meeting and includes the text of the 16 recommendations.

Antarctic Treaty nations meet in Belgium; adopt 16 recommendations

With representatives of the 32 parties to the Antarctic Treaty in attendance, the 13th Antarctic Treaty Consultative Meeting took place in Brussels, Belgium, 7-19 October 1985. Discussion centered on improving operation of the Antarctic Treaty system and preventing harmful impacts on the antarctic environment as a result of human activities. The meeting elaborated 16 recommendations to governments on these and other subjects.

The Brussels meeting was convened pursuant to Article IX of the Antarctic Treaty, which provides for regular meetings for exchanging information and consultations

and for formulating, considering, and recommending measures to further the principles and objectives of the Treaty. Representatives of the 18 Antarctic Treaty Consultative Parties participated; they are Argentina, Australia, Belgium, Brazil, Chile, China, Federal Republic of Germany, France, India, Japan, New Zealand, Norway, Poland, South Africa, U.S.S.R., United Kingdom, United States, and Uruguay. Two nations—China and Uruguay—participated as consultative parties for the first time, their consultative status having been recognized at a special meeting just before the consultative meeting. Observers attended from the 14 parties to the

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Antarctic Treaty that are not consultative parties. These nations are Bulgaria, Cuba, Czechoslovakia, Denmark, Finland, German Democratic Republic, Hungary, Italy, Netherlands, Papua New Guinea, Peru, Romania, Spain, and Sweden.

Belgian Foreign Minister Leo Tindemans welcomed participants with an address highlighting the contributions of the Antarctic Treaty system both to international peace and cooperation and to the growth of scientific knowledge. He announced resumption of scientific research programs in Antarctica by Belgian scientists. Following Foreign Minister Tindemans' address, the meeting adopted an agenda that had been drawn up at a preparatory meeting in April 1985:

- (1) Opening of the meeting
- (2) Election of officers
- (3) Opening addresses
- (4) Adoption of the agenda
- (5) Operation of the Antarctic Treaty system
- (6) Public availability of the documents of consultative meetings
- (7) Exchange of information in accordance with the Antarctic Treaty
- (8) Improvement of telecommunications in Antarctica and collection and distribution of meteorological data
- (9) Man's impact on the antarctic environment
- (10) Sites of Special Scientific Interest (SSSIs) and Specially Protected Areas (SPAs)
- (11) Effects of tourism and nongovernmental expeditions in the Antarctic Treaty area
- (12) Matters relating to the appointment of observers at consultative meetings
- (13) Uses of antarctic ice
- (14) Antarctic resources: the question of mineral exploration and exploitation (procedural items only)
- (15) Historic monuments
- (16) Inspections under Article VII of the Antarctic Treaty
- (17) Date and place of next consultative meeting
- (18) Any other business
- (19) Adoption of final report
- (20) Closing of the meeting

Paul Hubin, the representative of Belgium, was elected chairman. Most substantive agenda items were considered in two working groups. Rolf Trolle Andersen of Norway chaired a group that dealt with the operation of the Antarctic Treaty system (item 5), the public availability of consultative meeting documents (item 6), the exchange of information in accordance with the Antarctic Treaty (item 7), matters relating to the appointment of observers at consultative meetings (item 12), and inspections under Article VII of the Antarctic Treaty (item 16). L. Felipe de Macedo-Soares of Brazil presided over the other working group, which covered man's impact on the antarctic environment (item 9), Sites of Special Scientific Interest (SSSIs) and Specially Protected Areas (SPAs) (item 10), the effects of tourism and nongovernmental expeditions in the Antarctic Treaty area (item 11), and historic monuments

(item 15). The remaining items were considered in plenary.

Availability of information

At the 12th meeting, held in Canberra in 1983, the United States as depositary government for the Antarctic Treaty had been asked to study the availability of information about the Antarctic Treaty system. As a result, in Brussels the United States tabled a paper (which had been discussed at the April preparatory meeting) that formed the basis for working group elaboration of what became Recommendation XIII-1. This recommendation calls for improving the final reports of consultative meetings and for making available, upon request, copies of final reports, the Antarctic Treaty handbook, and other documents. The recommendation also urges maintenance of up-to-date references on sources and repositories of antarctic data and information. It provides for designation of national contact points to carry out these functions.

Recommendation XIII-3 was developed to deal with the annual exchanges of information provided for under the Antarctic Treaty. The recommendation adjusts the target dates for such exchanges to consolidate modifications to previous-season activities with reports of planned activities. It also calls for increased attention to reporting tourist visits to Antarctica.

Pursuant to agreement reached at the 12th consultative meeting, the working group considered the public availability of the documents of the first three consultative meetings. It was agreed (and reflected in the final report) that working papers and information papers from those meetings would be made publicly available unless any consultative party notified the Government of Belgium by 31 December 1985 that it believed a particular paper or papers should not be released. The 14th meeting, in 1987, will review the documents of the fourth through the seventh consultative meetings.

Further views were exchanged on the preparation of a "white book," a compilation of information about Antarctica, which had been suggested at the 12th meeting. The prevailing view among the representatives was that the 30th anniversary (1991) of the entry into force of the Antarctic Treaty might be appropriate for issuance of such a publication. Questions were raised as to the content of a "white book" and how it would differ from the Antarctic Treaty Handbook. The parties decided to revisit the matter at the 14th meeting.

Based on a suggestion originally put forward by Chile, the working group developed a recommendation (approved as Recommendation XIII-2) calling for regular



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reports at future consultative meetings on the status and activities of various components of the Antarctic Treaty system. Such reports would ensure that the final report of each consultative meeting would relate activities of the Antarctic Treaty system as a whole in the previous biennium. Recommendation XIII-2 also invites the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Scientific Committee for Antarctic Research (SCAR) to designate observers to present reports on their activities. The invitation is the first provision for attendance by international organizations at regular consultative meetings.

Observers at meetings

The general question of observers at Consultative Meetings attracted considerable discussion in the Andersen working group. The working group drafted a recommendation (approved as Recommendation XIII-15) that calls for invitations to nonconsultative parties to attend consultative meetings as observers on a continuing basis. Previously, such invitations had been extended on a meeting-by-meeting basis.

Representatives discussed extensively their views on attendance by observers from international organizations. The United States and other consultative parties emphasized the conclusion in the final report of the 12th meeting that international organizations that could contribute to the substantive work of a particular consultative meeting should be invited to attend that meeting as observers. The United States, therefore, supported attendance by observers from organizations in addition to CCAMLR and SCAR as provided for in Recommendation XIII-2. Other consultative delegations, however, took a more cautious approach, preferring to delay consideration of additional international organizations. As reflected in the final report, the delegations did agree that draft revisions to the rules of procedure for consultative meetings dealing with attendance by international organization observers would be prepared and circulated before the next preparatory meeting.

The Andersen working group also discussed establishing a permanent infrastructure (possibly a secretariat) for the Antarctic Treaty consultative mechanism. This discussion included related suggestions for more frequent Consultative Meetings and the sharing of their costs. No specific proposals emerged from the working group's deliberations, but the consultative parties identified these issues for priority attention at the 14th meeting.

The item on inspections under the Antarctic Treaty drew brief working group discussion. The United States suggested

a reference to the importance of regular exercise of the on-site inspection rights contained in the Antarctic Treaty; it was agreed to insert this in the final report. There was also a preliminary exchange of views on the feasibility and desirability of consultative parties conducting joint inspections.

Environmental protection

The working group chaired by L. Felipe de Macedo-Soares concentrated on matters relating to the protection of the antarctic environment. The group gave detailed attention to Sites of Special Scientific Interest (SSSIs) and Specially Protected Areas (SPAs)—systems that have evolved within the consultative mechanism to preserve areas of particular value for specific scientific studies and areas of particular ecological sensitivity from harmful human impact or interference. Basing its work on the detailed advice of SCAR, the working group prepared recommendations (approved as Recommendations XIII-7 through XIII-14) that designate three new SPAs and 13 new SSSIs, modify one SPA, extend the duration of seven SSSIs, and amend and extend the duration of another SSSI.

As at the 12th meeting, representatives continued to disagree over the designation of SSSIs wholly or predominantly located in marine areas. Three such sites had been recommended by SCAR, but there was no consensus to approve their designation.

The working group also analyzed the need for an additional category or categories of protected areas to supplement the system of SPAs and SSSIs. Australia had suggested a new category of "managed areas." The United States, taking a somewhat different approach, emphasized the need to develop and integrate the data necessary to make determinations about protected areas, as well as to ensure consistency among various activities in Antarctica. Consideration of these matters resulted in Recommendation XIII-5, which requests the advice of SCAR.

Also considered were preliminary guidelines developed by SCAR that suggest that the Consultative Parties consider updating the existing code of conduct for antarctic expeditions and station activities. It was agreed that this task should await completion of the detailed review of the code of conduct being undertaken by SCAR. A recommendation referring the matter to SCAR was elaborated and approved as Recommendation XIII-4.

The Macedo-Soares working group debated the question of concentration in the siting of stations in Antarctica. The subject, originally raised by Chile, was referred to plenary for development of a recom-

SSSIs extended; new SSSIs and SPAs recommended

During the Brussels meeting, representatives recommended that the dates of expiration for eight existing Sites of Special Scientific Interest (SSSIs) in Antarctica be extended. They also recommended that 13 new ones be established. SSSIs are places where scientific investigations might suffer from interference unless protected by a specific management plan.

Additionally, the 13th meeting proposed three new Specially Protected Areas (SPAs) in Antarctica and recommend extending the area of one SPA (Cape Hallett). This brings the total number of SPAs to 20. SPAs are areas of outstanding scientific interest that are accorded special protection to preserve their unique natural system.

The SSSIs that have had dates of expiration extended and the new SSSIs and SPAs appear in the Treaty recommendations section that begins on page 4.

mentation. After extensive informal consultation, Recommendation XIII-6 was adopted: it calls for consultations among those nations operating scientific stations in the same vicinity to avoid environmental or logistics problems and possible interference with scientific research.

The working group did further work on environmental impact assessment procedures to apply to research and related support in Antarctica. At the request of the 12th meeting, SCAR had drawn up suggested guidelines. Though a specific recommendation did not emerge on the procedures, the SCAR-suggested guidelines (tabled by the United Kingdom) were attached to the final report, which reaffirmed commitment to environmental impact assessment.

Other issues

Finally, the working group considered historic monuments and tourism. It prepared a consolidated recommendation (adopted as Recommendation XIII-16), designating Belgian, French, Chinese, and Polish historic monuments in Antarctica and

called for a review at the 14th meeting of the need to combine and, where appropriate, update existing recommendations relating to tourism.

The remaining agenda items— telecommunications, use of antarctic ice, and mineral exploration and exploitation— were not the subject of specific proposals. The first two had been discussed intensely at the last consultative meeting, and further actions were not felt necessary at the 13th meeting. They will be kept under scrutiny at the next meeting.

A regime for antarctic mineral resources is the subject of detailed and ongoing negotiations in a separate special consultative meeting. Consideration of this item at the Brussels meeting was therefore procedural, but it offered France the opportunity to report on the last round in the mineral resource negotiations, which had taken place in Paris. The final report welcomed the progress being made in those negotiations and underlined their importance.

The 13th Antarctic Treaty consultative meeting took important steps in develop-

ment of measures relating to the protection of the antarctic environment and the operation of the Antarctic Treaty system. It also identified priority issues for attention at the next consultative meeting, which will take place in Brazil in 1987. The parties welcomed the offer of Brazil to host this meeting.

—R. Tucker Scully, Director, Office of Oceans and Polar Affairs, Department of State, Washington, D.C. 20520.

The text of the 16 recommendations adopted at the meeting follows this article; annexes and maps referred to in the recommendations have not been included. Copies of the final report of the 13th Antarctic Treaty consultative meeting, including the 16 recommendations, maps and annexes, may be obtained from the Polar Information Program, National Science Foundation, Washington, D.C. 20550 (202/357-7817).

13th Consultative Meeting recommendations

XIII-1. Operation of the Antarctic Treaty System: Information

The Representatives,

Recalling Recommendation XII-6;

Recognizing the importance of accurate and adequate information regarding the Antarctic Treaty System,

Noting therefore the desirability of ensuring and facilitating the availability of information about the Antarctic Treaty System;

Recommend to their Governments that:

(1) Efforts be continued to ensure that final reports of Consultative Meetings provide full and accurate records of these meetings, including:

(a) the general trends of discussion of the specific agenda items considered as well as specific steps or actions taken as a

result of decisions or recommendations adopted at previous consultative meetings; and

(b) appropriate additional documentation of the meeting;

(2) The Antarctic Treaty Handbook be regularly maintained as a current compilation of the recommendations and other actions agreed by Consultative Meetings;

(3) To the greatest extent practicable and feasible and in accordance with national laws and regulations, the following be made available on request:

(a) Final reports of Consultative Meetings,

(b) The Antarctic Treaty Handbook,

(c) Annual exchanges of information they provide under the Antarctic Treaty;

(4) Their national committees be encouraged to make available, on request and in

accordance with national laws and regulations, annual activities reports which these committees submit to the Scientific Committee on Antarctic Research (SCAR);

(5) On request and in accordance with national laws and regulations, up-to-date information be made available, to the greatest extent practicable and feasible, on:

(a) the location of depositories of data, samples, and collections resulting from scientific research in Antarctica, and

(b) the nature and location of bibliographies or other information sources concerning reports and published works related to antarctic matters, including those related to scientific research activities in Antarctica;

(6) A national contact point, or contact points, be designated and charged with the functions referred to in paragraph 3 above and maintaining the information referred to in paragraph 5 above;

(7) The names and addresses of the institutions or entities designated as national contact points, pursuant to paragraph 6 above, be published as an annex to the final report of each Consultative Meeting and the Antarctic Treaty Handbook and be otherwise publicly disseminated.

XIII-2. Operation of the Antarctic Treaty System: Overview

The Representatives,

Recognizing the virtue of there being a regular overview of the Antarctic Treaty System, including the relationships among its components;

Believing that regular reports about the activities of these components at the Consultative Meetings would serve this objective;

Recommend to their Governments that:

(1) An item, "Operation of the Antarctic Treaty System: Reports," be included on the Agenda of each subsequent Consultative Meeting;

(2) Under that item reports concerning developments in their respective areas of competence since the previous Consultative Meeting be received from the components of the system and that, to this end:

(a) they request the Chairman of any special Consultative Meeting, and of any other meeting held pursuant to a Recommendation of a Consultative Meeting, or a person designated by him, to present such a report;

(b) they invite the Commission for the Conservation of Antarctic Marine Living Resources to appoint its Chairman or other person to represent the Commission as an observer for the specific purpose of presenting such a report;

(c) through their National Committees, they invite the Scientific Committee on Antarctic Research (SCAR) to appoint its President or other persons to represent the Committee as an observer for the specific purpose of reporting on:

(i) the general proceedings of SCAR;

(ii) matters within the competence of SCAR under the Convention for the Conservation of Antarctic Seals;

(iii) such publications and reports as may have been published or prepared in accordance with Recommendations IV-19 and VI-9 respectively;

(d) pending possible establishment of a Commission as provided for under the Convention for the Conservation of Antarctic Seals, they invite the Depositary Government of that Convention to report on the matters within the Depositary's competence under the Convention.

(3) In preparing for each Consultative Meeting they consider, in relation to developments since the previous Consultative Meeting, whether, for the purpose of such overview, reports on any such developments in, or bearing upon, the Antarctic Treaty System would be helpful and, through the host Government for that Consultative Meeting, act accordingly.

XIII-3. Exchange of information in accordance with the Antarctic Treaty: annual exchanges

The Representatives,

Recalling Articles III and VII of the Antarctic Treaty and Recommendations VIII-6 and VIII-9;

Considering that while it is important that Consultative Parties should continue to report extensions, reductions, or other modifications of activities previously reported, no practical purpose is served by requiring this information to be provided in the antarctic winter;

Recalling the need to maintain an awareness of the activities of tourists in the Antarctic Treaty area;

Recommend to their Governments that the Annex to Recommendation VIII-6 be amended as follows:

Paragraph 2: replace the date "30 June" with the date "30 November";

Paragraph 3: add XVI. The reports referred to in paragraph 3 of Recommendation VIII-9.

XIII-4. Man's impact on the antarctic environment: Code of conduct for antarctic expeditions and station activities: waste disposal

The Representatives,

Recalling Recommendations VI-4, VIII-11 and XII-4;

Recognizing that Antarctica derives much of its scientific importance from its uncontaminated condition and the consequent need to reduce to the minimum level practicable the spread of all potential contaminants introduced into the Antarctic Treaty area by man;

Noting that changes have occurred in the perception of what constitutes pollution and in analytical techniques since Recommendation VIII-11 was approved;

Noting with appreciation the preliminary review by the Scientific Committee on Antarctic Research (SCAR) of the waste disposal aspects of the Annex to Recommendation VIII-11;

Recommend to their respective Governments that through their National Antarctic Committees they invite SCAR, using all resources available to it, to undertake a comprehensive review of the waste disposal aspects of the Annex to Recommendation VIII-11 and, giving due consideration to the need to avoid detrimental effects on neighboring or associated ecosystems outside the Antarctic Treaty area and to considerations of cost-effectiveness, to offer:

(i) scientific advice regarding waste disposal procedures and standards that it is desirable to achieve at coastal and inland stations and field camps;

(ii) advice regarding the logistics feasibility of such procedures bearing in mind antarctic operational circumstances, including variation in the numbers of personnel between stations, operational and logistics difficulties, and local circumstances; and

(iii) such other advice as seems to SCAR to be relevant to waste disposal procedures.

XIII-5. Man's impact on the antarctic environment: Additional protective arrangements

The Representatives,

Recalling the measures adopted under the Antarctic Treaty for the protection of the environment, the protection of historic sites and monuments, the conservation of fauna and flora, and in particular the setting aside of Specially Protected Areas and Sites of Special Scientific Interest;

Desiring to ensure that activities in Antarctica should not harm the unique antarctic environment, disrupt scientific investigation or other legitimate uses, or be otherwise contrary to the principles and purposes of the Antarctic Treaty;

Bearing in mind that the Scientific Committee on Antarctic Research at the XVIIIth Meeting in Bremerhaven considered the question of the establishment of a new type of conservation area in the Antarctic;

Recommend to their Governments that through their National Committees they invite the Scientific Committee on Antarctic Research (SCAR) to offer scientific advice:

(i) on the system of protected areas in the Antarctic, including Sites of Special Scientific Interest and Specially Protected Areas and the question of a possible additional category of area under a different form of protection; and

(ii) on steps that possibly could be taken to improve the comparability and accessibility of scientific data on Antarctica.

XIII-6. Facilitation of Scientific research: Siting of stations

The Representatives,

Recalling Recommendations I-1, VI-4, VII-1, VII-8, VIII-11 and XII-3;

Reaffirming that freedom of scientific investigation as set out in Article II of the Antarctic Treaty is one of the fundamental principles of the Treaty; and

Recognizing that, while there are scientific, environmental, and logistics advantages to be gained from stations being in proximity to one another, there can also be disadvantages which can be avoided by appropriate consultation;

Recommend to their Governments that where stations have been established in the same vicinity the concerned national antarctic operating agencies should consult together, by whatever means found appropriate, so as to safeguard existing scientific activities, avoid operational logistic difficulties, and avoid undue adverse environmental effects arising from cumulative impacts.

XIII-7. Facilitation of Scientific research: Sites of Special Scientific Interest: interim guidelines: extension of designation

The Representatives,

Recalling Recommendations VIII-3, VIII-4, X-6 and XII-5;

Noting that:

(i) In accordance with paragraph 2 of Recommendation VIII-3 the Scientific Committee on Antarctic Research (SCAR), at its Eighteenth Meeting at Bremerhaven in September 1984, had reviewed the eight Sites of Special Scientific Interest designated in Recommendation VIII-4.

(ii) Experience of the practical effect of the management plans for these sites had shown them to be an effective means of reducing the risks of harmful interference in areas of special scientific interest.

(iii) Except for Site No. 1 no change to these management plans had been proposed by SCAR.

Recommend to their Governments that:

(1) The date of expiry of designation of Site Numbers 2-8 be extended from 31 December 1985 to the date shown below:

Site No. 2: Arrival Heights, Hut Point Peninsula, Ross Island: to 31 December 1987.

Site No. 3: Barwick Valley, Victoria Land: to 31 December 1995.

Site No. 4: Cape Crozier, Ross Island: to 31 December 1991.

Site No. 5: Fildes Peninsula, King George Island, South Shetland Islands: to 31 December 1991.

Site No. 6: Byers Peninsula, Livingston Island, South Shetland Islands: to 31 December 1991.

Site No. 7: Haswell Island: to 31 December 1991.

Site No. 8: Western shore of Admiralty Bay, King George Island, South Shetland Islands: to 31 December 1995.

(2) They use their best endeavors to ensure, in accordance with paragraphs 3 and 4 of Recommendation VII-3, that the management plans of these sites are observed.

XIII-8. Facilitation of scientific research: Sites of Special scientific interest interim guidelines: additional sites

The Representatives,

Recalling Recommendations VII-3, VIII-3, VIII-4 and X-5;

Noting that management plans have been prepared and approved by the Scientific Committee on Antarctic Research for certain Sites of Special Scientific Interest additional to those already designated;

Considering that it would be advantageous to gather experience of the practical effect of the management plans prepared for these Sites;

Recommend to their Governments that they voluntarily take account of the management plans, annexed to this Recommendation, for the following Sites:

Site No. 9: Rothera Point, Adelaide Island

Site No. 10: Caughley Beach, Cape Bird, Ross Island

Site No. 11: Tramway Ridge, Mount Erebus, Ross Island

Site No. 12: Canada Glacier, Lake Fryxell, Taylor Valley, Victoria Land

Site No. 13: Potter Peninsula, King George Island, South Shetland Islands

Site No. 14: Harmony Point, Nelson Island, South Shetland Islands

Site No. 15: Cierva Point and nearby islands, Danco Coast, Antarctic Peninsula

Site No. 16: Bailey Peninsula, Budd Coast, Wilkes Land

Site No. 17: Clark Peninsula, Budd Coast, Wilkes Land

Site No. 18: White Island, McMurdo Sound

Site No. 19: Linnaeus Terrace, Asgaard Range, Victoria Land

Site No. 20: Biscoe Point, Anvers Island, Palmer Archipelago

Site No. 21: Shores of Port Foster Deception Island, South Shetland Islands.

XIII-9. Facilitation of scientific research: Sites of special scientific interest interim guidelines: SSSI No. 1: Cape Royds, Ross Island: amendment to management plan

The Representatives,

Recalling Recommendations VIII-4 and the Management Plan for Site of Special Scientific Interest No. 1: Cape Royds, Ross Island annexed thereto;

Noting that at its Eighteenth Meeting the Scientific Committee on Antarctic Research (SCAR) held at Bremerhaven in September 1984 reviewed the management plans of the eight Sites of Special Scientific Interest designated in Recommendations VIII-4 and X-5 and that it proposed an amended management plan for SSSI No. 1: Cape Royds, Ross Island;

Recommend to their Governments that:

(1) The management plan for Site of Special Scientific Interest No. 1: Cape Royds, Ross Island annexed to Recommendation VIII-4 be terminated;

(2) They voluntarily take account of the management plan, annexed to this Recommendation, for Site No. 1: Cape Royds, Ross Island.

XIII-10. Specially protected areas North Coronation Island, South Orkney Islands

The Representatives,

Considering that the area bounded by Foul Point and Conception Point on the

north coast of Coronation Island, South Orkney Islands, extending southwards to Wave Peak and comprising Ommaney Bay and the bay between Prong Point and Conception Point embraces areas of coastal ice-free terrain (Conception, Prong and Foul Points) with large seabird colonies and lichen-dominated cliffs, and permanent ice rising to the Brisbane Heights plateau which provides an excellent representative area of a pristine ice environment near the northern limit of the maritime Antarctic and the Antarctic Treaty Area, and that the interrelated terrestrial, permanent ice and marine components of this area comprise an integrated example of the coastal, permanent ice, and sublittoral ecosystems typical of the maritime antarctic environment;

Recommend to their Governments that the following area of outstanding scientific interest be inserted in Annex B, Specially Protected Areas, of the Agreed Measures for the Conservation of Antarctic Fauna and Flora:

Specially Protected Area No. 18 North Coronation Island, South Orkney Islands. Between latitude 60°31'S, longitude 45°41'W and latitude 60°37'S, longitude 45°36'W and latitude 60°32'S, longitude 45°29'W.

Description: The area lies on the central north side of Coronation Island, South Orkney Islands. It is bounded to the east by Foul Point (latitude 60°32'S, longitude 45°29'W) and to the west by Conception Point (60°31'S 45°41'W); the entire area of these points is included in the area. The eastern boundary follows a precipitous ridge 6 kilometers southwards to a position at 2,500 feet (750 meters) altitude immediately to the west of Mt. Nivea summit (60°35'S 45°29'W), thence at 3,000 feet (700 meters) altitude to the northeast of Wave Peak summit (60°37'S, 45°29'W), and from there 4 kilometers westwards across the Brisbane Heights plateau then 4 kilometers north-northwest to an unnamed summit at 3,532 feet (1,060 meters) and north for 6 kilometers to Conception Point. The summits of Mt. Nivea and Wave Peak and the col known as High Stile are outside the area. Ommaney Bay and the unnamed bay to the west are included within the area south of the boundary between Conception and Prong Points (11.5 kilometers). The area is shown on the attached map.

XIII-11. Specially protected areas: Lagotellerie Island, Marguerite Bay

The Representatives,

Considering that Lagotellerie Island contains a relatively diverse flora and fauna typical of the southern Antarctic Peninsula region; that of particular interest is the abundance of the only two Antarctic flowering plants *Deschampsia antarctica* and *Colobanthus quitensis* which form closed stands up to 10 square meters; that these are amongst the largest stands known south of the South Shetland Islands, being only 90 kilometers north of their southern limit; that here both species flower profusely and the seeds have a greater viability than those produced in the South Orkney and South Shetland Islands; that numerous mosses and lichens also form well developed communities on the island; that a few of the mosses are fertile, a rare phenomenon in most antarctic localities; that the invertebrate fauna is rich and that the island is one of the southernmost sites for the apterous midge *Belgica antarctica*; that the shallow loamy soil developed beneath these swards and its associated invertebrate fauna and microbiota are probably unique at this latitude; that there is a colony of about 1000 Adélie penguins *Pygoscelis antarctica* and one of the farthest south colonies of a few dozen blue eyed cormorants *Phalacrocorax atriceps* at the southeast corner of the island and that numerous pairs of brown and south polar skuas *Catharacta lonnbergi* and *C. macrormicki* breed on the island;

Recommend to their Governments that the following area of outstanding scientific interest be inserted in Annex B, Specially Protected Areas, of the Agreed Measures for the Conservation of Antarctic Fauna and Flora:

Specially Protected Area No. 19: Lagotellerie Island, Marguerite Bay latitude 67°53'S, longitude 67°24'W.

Description: The area consists of Lagotellerie Island which lies about 3 kilometers west of the southern part of Horseshoe Island, Marguerite Bay, southwest Antarctic Peninsula. The area is shown on the attached map.

XIII-12. Specially protected areas: "New College Valley," Caughley Beach, Cape Bird, Ross Island

The Representatives,

Considering that the area contains some of the most luxuriant stands of vegetation

(algae, mosses and lichens) and associated microflora and microfauna in the Ross Sea sector of Antarctica; that because of the susceptibility of the cryptogamic vegetation to damage from trampling, the designation of the area provides protection for its biota, so that the area may serve as a conservation reserve representative of the adjacent Site of Special Scientific Interest No. 10;

Recommend to their Governments that the following area of outstanding scientific interest be inserted in Annex B, Specially Protected Areas, of Agreed Measures for the Conservation of Antarctic Flora and Fauna:

Specially Protected Area No. 20: "New College Valley," Caughley Beach, Cape Bird, Ross Island, latitude 77°14'S, longitude 166°23'E.

Description: The area consists of the ice free terrain lying between the cliff top above Caughley Beach and about 100 meters east of the Mt. Bird ice cap, and between a line south of the main stream bed of "Kebble Valley" and the south ridge of "New College Valley." It is surrounded on three sides by Site of Special Scientific Interest No. 10. The area is shown on the attached map.

XIII-13. Specially protected areas: Cape Hallett, Victoria Land: extension of boundaries

The Representatives,

Recalling Recommendation IV-7 in accordance with which an area between the eastern side of the road, which runs along the eastern side of Willett Cove, and the western margin of the permanent ice sheet, to the south of a line from the road to the margin of the permanent ice sheet at the latitude of the head of Willett Cove, and to the north of a line from the road to the margin of the permanent ice sheet drawn 350 meters to the south of that latitude and parallel to it, was designated for insertion in Annex B, Specially Protected Areas, of the Agreed Measures for the Protection of Antarctic Fauna and Flora on the grounds that Cape Hallett includes a small patch of particularly rich and diverse vegetation which supports a variety of terrestrial fauna and that the ecosystem, which includes a rich avifauna, is of outstanding scientific interest;

Considering that in recent years rich areas of vegetation have developed immediately

outside the existing boundaries of the area; that to the south is a particularly dense and extensive stand of moss below a large permanent snow patch on the talus slope below the north end of the ice-fall; that the main moss stand is 35 meters across but plants are widely scattered on ridges and in gullies throughout the area; that to the north, rock outcrops and stable scree support extensive stands of dense lichen growth (especially *Xanthoria*) and mosses, that algae *Prasiola* are also present, and that these are some of the richest stands of vegetation in Victoria Land;

Recommend to their Governments that the Description of Specially Protected Area No. 7, Cape Hallett, Victoria Land, inserted in Annex B, Specially Protected Areas, of the Agreed Measures for the Conservation of Antarctic Fauna and Flora be amended as follows:

Description: The area comprising a roughly rectangular block lies south of the northern coast of Cape Hallett between the road, which runs along the eastern side of Willett Cove and the western margin of the permanent ice sheet and to the north of an E-W line from a projection of the line of the road southward to a point 200 meters south of latitude 72°18'S to the margin of the permanent ice sheet. The original area and the revised boundaries are shown on the attached map.

XIII-14. Specially protected areas: interim guidelines

The Representatives recommend to their Governments that, until such time as Recommendations XIII-10 to XIII-13 may become effective in accordance with Article IX of the Antarctic Treaty, they should as far as feasible consider these Recommendations as guidelines.

XIII-15. Matters relating to the appointment of observers at consultative meetings

The Representatives,

Taking note of Article IX of the Antarctic Treaty;

Noting also that all Contracting Parties to the Antarctic Treaty have rights and obligations under the Treaty and are, as Parties, bound to carry out its provisions and uphold its purposes and principles, and to maintain and strengthen that Treaty;

Recalling that the non-Consultative Parties to the Antarctic Treaty were invited

to attend the twelfth and thirteenth Consultative Meetings, as well as the Preparatory Meeting of the thirteenth Consultative Meeting;

Noting that accordingly the Rules of Procedure have been appropriately amended;

Recognizing the valuable contribution made to the deliberations of the twelfth and thirteenth Consultative Meetings by the representatives of the non-Consultative Parties;

Recommend to their Governments that the Government of the host country of each future regular Consultative Meeting invite non-Consultative Parties to appoint representatives to attend the Meeting, and any associated Preparatory Meeting, in accordance with the relevant provisions of the Rules of Procedure.

XIII-16. Historic sites and monuments

The Representatives,

Recalling Recommendations I-IX, V-4, VI-14, VII-9 and XII-7;

Recommend to their Governments that the following historic monuments be added to the "List of Historic Monuments Identified and Described by the Proposing Government or Governments" annexed to Recommendation VII-9 and that thereafter they be accorded the respect and protection required by the Recommendations recalled above:

(45) Plaque on Brabant Island, on Metchnikoff Point, latitude 64°02'S, longitude 62°34'W, mounted at a height of 70 meters on the crest of the moraine separating this point from the glacier and bearing the following historic monuments be added to the "List of Historic Monuments Identified and Described by the Proposing Government or Governments" annexed to Recommendation VII-9 and that thereafter they be accorded the respect and protection required by the Recommendations recalled above:

(45) Plaque on Brabant Island, on Metchnikoff Point, latitude 64°02'S, longitude 62°34'W, mounted at a height of 70 meters on the crest of the moraine separating this point from the glacier and bearing the following inscription: "This monument was built by Francois de Gerlache and other members of the joint services expedition 1983-85 to commemorate the first landing on Brabant Island by the Belgian Antarctic Expedition 1897-99:

Adrien de Gerlache (Belgium) leader

Roald Amundsen (Norway)

Henryk Arctowski (Poland)

Frederick Cook (U.S.A.) and

Emile Danco (Belgium)

camped nearby from 30 January to 6 February 1898."

(46) All the buildings and installations of Port Martin base - Terre Adélie (latitude 66°49'S, longitude 141°24'E) constructed in 1950 by the 3rd French expedition in Terre Adélie and partly destroyed by fire during the night of 23 to 24 January 1952.

(47) Wooden building called "Base Marret" on the Ile des Petrels off Terre Adélie (latitude 66°40'S, longitude 140°01'E) where seven men under the command of Mario Marret overwintered in 1952 following the fire at Port Martin base.

(48) Cross erected on the north-east headland of the Ile des Petrels - Terre Adélie (latitude 66°40'S, longitude 140°01'E) in memory of Andre Prudhomme, head meteorologist in the 3rd International Geophysical Year expedition who disappeared during a storm on 7 January 1959.

(49) The concrete pillar erected by the First Polish Antarctic Expedition at Dobrolowski station on the Bunker Hills to measure acceleration due to gravity $g = 982,349.4$ milligals plus or minus 0.4 milligals in relation to Warsaw, according to the Potsdam system, in January 1959 (latitude 66°16.3'S, longitude 100°45'E, $h = 35.4$).

(50) A commemorative plaque bearing the Polish eagle, the national emblem of Poland, the dates 1975 and 1976, and the following text in Polish, English and Russian: "In memory of the landing of members of the first Polish Antarctic marine research expedition on the vessels 'Profesor Siedlecki' and 'Tazar' in February 1976." This plaque is mounted on a shore cliff on Fildes Peninsula, King George Island, Maxwell Bay, south-west of the Chilean and Soviet stations.

(51) The grave of Wladzimir Puchalski, surmounted by an iron cross, on a hill to the south of Arctowski station on King George Island. W. Puchalski was an artist, a producer of documentary nature films, who died on 19 January 1979 whilst working at the station.

(52) Monolith erected to commemorate the establishment on 20 February 1985 by the People's Republic of China of the "Great Wall Station" (latitude 62°13'S, longitude 58°58'W) on Fildes Peninsula, King George Island, in the South Shetland Islands. Engraved on the monolith is the following inscription in Chinese: "Great Wall Station, First Chinese Antarctic Research Expedition, 20 February 1985."

Emergency assistance in Antarctica

Anyone who has travelled south of 60°S latitude recognizes the hazards presented by the antarctic environment. Weather and ice conditions are unpredictable. Stations and field camps are isolated, and the equipment that supports them is under constant environmental stress. More importantly, in an emergency assistance, often is difficult to obtain.

In 1957 the United States and 11 other nations established research stations to conduct research in Antarctica during the International Geophysical Year. Today 16 countries (Argentina, Australia, Brazil, Chile, the People's Republic of China, the Federal Republic of Germany, France, India, Japan, New Zealand, Poland, South Africa, the Union of Soviet Socialist Republics, the United Kingdom, the United States of America, and Uruguay) maintain antarctic stations and support research programs. All of these programs work within the framework of an international agreement, the Antarctic Treaty.

Among the Treaty's provisions is the exchange of technical and scientific information. Over the last two decades other agreements have been developed among the Treaty consultative parties. These include the exchange of personnel and logistics support, as well as support during emergencies.

During the 1985-1986 austral summer, the U.S. Government responded to four requests for emergency assistance from antarctic programs of 3 other countries and one request from a private expedition. Each of these occasions demonstrates the ability of the U.S. program to respond quickly and effectively in an emergency.

Fuel and supplies for Marsh Station

In late October 1985 the U.S. embassy in Santiago, Chile, received an urgent request from the Chilean government for assistance in obtaining fuel and equipment for their airfield at Marsh Station on King George Island (62°S 58°15'W) near the Antarctic Peninsula. Because of heavy snowfall and equipment failure, station personnel could not make the station runway ready for use. The Chileans asked if *Polar Duke*, an ice-strengthened research ship leased by the United States for work in the Antarctic Peninsula region, could deliver the needed materials.

Polar Duke, which had just completed a visit to Ushuaia, Argentina, was able to sail to Punta Arenas, Chile, and pick up 17 tons of snow removal equipment and

41,000 gallons of fuel. With this assistance the personnel of the Chilean Antarctic Program were able to remove the snow from the runway and begin their austral summer program.

The U.S. and Chilean governments have established various agreements for logistics and support in the Antarctic Peninsula region. Each year U.S. personnel make use of Chilean airplane flights to King George Island from which they are transported by *Polar Duke* to Palmer Station. Chilean scientists often work with U.S. scientists on field research.

Airplane parts for Rothera Station

Shortly after this, the British Antarctic Survey (BAS) informed the U.S. government that three of their Twin Otter airplanes based at Rothera Station on Adelaide Island (67°15'S 68°30'W) had been damaged in a storm. Besides supporting the British program, these airplanes were to have been used by U.S. and British geologists and geophysicists for an aeromagnetic survey of Ellsworth Land during the 1985-1986 austral summer.

Officials of the British program requested that the Twin Otter, leased by the United States to support glaciology projects at Siple Coast, pick up parts in Florida on the way south and deliver them to Rothera Station. After it was determined that the weight of the repair parts would not interfere with the operation of the U.S. Twin Otter, the parts were acquired in the United States and delivered to the British station.

Davis Station medical evacuation

On 29 October McMurdo Station personnel received an urgent message via New Zealand's Scott Base from the Australian station Davis (68°34'S 77°57'E). A member of the Australian National Antarctic Expedition had been severely burned, and medical facilities to treat the injured man were not available in Antarctica. The Australians asked if one of the U.S. Antarctic Program ski-equipped Hercules (LC-130) airplanes could be flown from McMurdo to the Australian station, which is on the Indian Ocean coast of Antarctica 2,334 kilometers from McMurdo, to evacuate the injured man to New Zealand.

U.S. Navy pilots were able to reach Davis Station, pick up the accident victim, and return to McMurdo Station without complications. Unfortunately, over 70 percent of the man's body had been burned, and

he had suffered inhalation burns in his lungs. Despite the efforts of the U.S. aircrew and medical team, the injured man died before the airplane reached McMurdo. (See accompanying article for details of the evacuation.)

Assistance to John Biscoe

On 13 November 1985 while sailing for Rothera Station near the Antarctic Peninsula, the British Antarctic Survey (BAS) ship *John Biscoe* was beset 4 miles from the ice edge near Adelaide Island. Although the ship tried to maneuver out of the pack ice, by 15 November northerly winds closed the leads in the ice and trapped the ship. That evening the captain notified BAS that the ship was drifting towards icebergs 3 miles away.

The U.S. research ship *Polar Duke*, which was 20 hours away from the beset ship, answered the British request for assistance. Although *Polar Duke* was able to reach *John Biscoe*, it could not free the British ship, which continued to drift closer to the icebergs. The captain was directed by BAS to take all crew and passengers off the ship. The crew and passengers were moved to *Polar Duke* and transported to Palmer, the U.S. station on Anvers Island.

Also working near the Antarctic Peninsula at this time was the West German research ship *Polarstern*. Because the West German ship is an icebreaker, it was able to free *John Biscoe*. Finding no damage, the captain and 19 crew members decided to continue the voyage. After *Polarstern* escorted the British ship out of the pack ice, *John Biscoe* returned to Palmer Station to pick up the British personnel that had remained there and continued on to Rothera Station to bring supplies and the new station crew.

Private expeditions and antarctic hazards

John Biscoe was not the only ship during the 1985-1986 austral summer to confront the dangers of the antarctic pack ice. On 11 January 1986 at 11:37 p.m. (local McMurdo time), Amundsen-Scott South Pole Station relayed a request for assistance from *Southern Quest*, a ship supporting a private expedition, to the U.S. research station on Ross Island, McMurdo. The captain informed personnel at the South Pole that the ship was sinking rapidly. Personnel at McMurdo Station, the largest research station in the U.S. Antarctic Program, began immediately to plan the rescue. (See "Southern Quest rescue," this issue, for details.)

The *Southern Quest* was in Antarctica to support the private expedition "In the Footsteps of Scott." For 3 days before it sank, the ship was moored to an ice floe so that the expedition's Cessna 185 air-

U.S. program assists Australians at Davis Station

At approximately 9:40 a.m. on 29 October 1985, New Zealand personnel from Scott Base notified McMurdo Station that they had received a message about a possible medical emergency at the Australian station Davis (68°5'S 78°E). The Australians, who were attempting to contact McMurdo Station, reported that a member of their crew had been severely burned. They requested assistance from the U.S. program in moving the man to a location where he could be treated.

By 10 a.m. U.S. personnel at McMurdo Station had contacted the Australian station and had gathered information on the man's condition. The plan was to fly an ski-equipped Hercules (LC-130) airplane to Davis Station, pick up the injured man, return to McMurdo Station, and then fly on to Christchurch, New Zealand.

The injured man, a 34-year-old Stephen Bunning, had been burned when an explosion occurred in the metal water tank in which he was working. He had been spraying a volatile, water-proofing agent on the inside of the tank. When the explosion occurred, he was thrown just outside the tank where he was found shortly after the explosion on 28 October. He sustained burns over 70 percent of his body and suffered inhalation burns.

U.S. Antarctic Program (USAP) personnel gathered together the available information on Davis Station, the available communication and navigation frequencies, and surrounding terrain. Davis Station, which is 2,334 kilometers from McMurdo Station, is on the southern Indian Ocean coast of Antarctica. Two potential areas for a landing site were identified—one on the polar plateau 35 to 40 kilometers from the station and one on the sea ice along the shore. The plateau site was at the top of a 500-meter rise. Because the rise was steep and the terrain rugged, no one at Davis Station had visited the site during 1985. The Australians did not know the condition of the surface and suspected that part of the area consisted of blue ice that cannot be used as a landing surface. Much preparation also would have been required to make this site a usable skiway.

After the Australians determined the thickness of the sea ice, USAP personnel decided that the ice was thick enough and strong enough to be used as a landing area for an LC-130. At McMurdo Station a flight crew was assembled and briefed by the Commander of the Naval Support Force. U.S. personnel instructed the Australians to prepare a 5,000-by-150-foot skiway on the sea ice and mark the area so that it would be visible to the LC-130 pilots.

The distance to Davis Station, coupled with amount of time that the airplane would spend on the ground, was just outside the fuel capability of the airplane. Because Davis did not have the proper facilities for fueling an LC-130, refueling could not be accomplished there. To solve the fuel problem, the airplane carried a 500-gallon drum of diesel fuel. Although carrying the excess fuel did make the airplane about 9,000 pounds heavier than the recommended landing weight, Navy personnel believed this risk was within acceptable limits. Also, the pilots decided to secure three of the airplane's four engines while the LC-130 was on the ground and to fly at a speed that would conserve fuel.

The LC-130 left McMurdo Station at approximately 3 p.m. on 29 October. After a flight of about 7 hours they arrived at Davis Station. The Americans were met by the station manager who escorted the Navy flight surgeon and corpsman to the station to pick up the injured man. While the doctors prepared the patient to be transported to the airplane, the aircrew refueled the airplane from the internal drum. Although the station was only 1.5 miles away, 20 minutes were required to move the patient to the skiway so that he would not sustain any further injuries.

After a successful takeoff, the LC-130 began its trip back to McMurdo Station. During the flight, the surgeon and the corpsman gave the injured Australian emergency medications and CPR. However, the combination of severe, extensive burns and the injury to his lungs proved to be too much for him. Despite the efforts of U.S. and Australian personnel, Mr. Bunning died at about 12:30 p.m. before the airplane reached McMurdo Station.

Mr. Bunning is survived by a widow and three children. The Australian Antarctic Division plans to hold a memorial service and dedicate a commemorative plaque at its headquarters in March 1986.

plane could be unloaded. The airplane was to have flown to the South Pole to pick up two Englishmen (Robert Swan and Roger Mears) and one Canadian (Gareth Wood) who had walked 1,360 kilometers from Cape Evans on Ross Island to the South Pole. The intent of the three walkers was to retrace the route taken by Captain Robert F. Scott during the 1911-1912 race to reach the South Pole. They arrived at the South Pole safely on 11 January a short time after the captain of the *Southern Quest* had told South Pole and McMurdo stations that the ship was sinking.

Private expeditions and U.S. policy

The 1985-1986 experiences of both the government-supported programs and the private expedition highlight the hazards of living, working, and travelling in Antarctica. As Antarctica has become more accessible, the number of tourists and privately financed groups has grown. With this growth has come the increased potential for accidents.

The U.S. National Security Council with the U.S. Antarctic Policy Group, chaired by the Department of State with the National Science Foundation and the Department of Defense as members, has established U.S. policy for support of private expeditions. It has stated that "the clearly defined objectives of the U.S. Antarctic Program (USAP) and the logistics constraints and operational demands upon it are such that the United States Government must limit assistance to non-USAP activities in Antarctica to cooperative programs between USAP and the antarctic programs of other governments." In an emergency the U.S. program in Antarctica will help private expeditions, but the government reserves the right to bill the survivors for all or any of the rescue costs. This policy follows recommendations made at Antarctic Treaty Consultative Party meetings and is supported by other consultative parties.

What happened to the "Footsteps of Scott" expedition provides an example of how the unpredictable nature of the antarctic environment can affect operations. Although *Southern Quest* was not an ice-breaker, it was a somewhat ice-strengthened ship and did withstand the ice in the Ross Sea and McMurdo Sound earlier in 1985. However, during the 1985-1986 austral summer the pack ice was the heaviest recorded in 20 years of U.S. recorded ice observations.

The leaders of the "Footsteps of Scott" expedition were informed of the U.S. and New Zealand policy on private expeditions 3 years before they started their expedition. They chose to make the jour-

(Continued on page 15.)

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Until 1977 the Foundation published an author and subject indexes of each volume of the *Anatarctic Journal*; in the March 1983 issue (Volume XVIII, no. 1) the tables of contents for 24 issues were published.

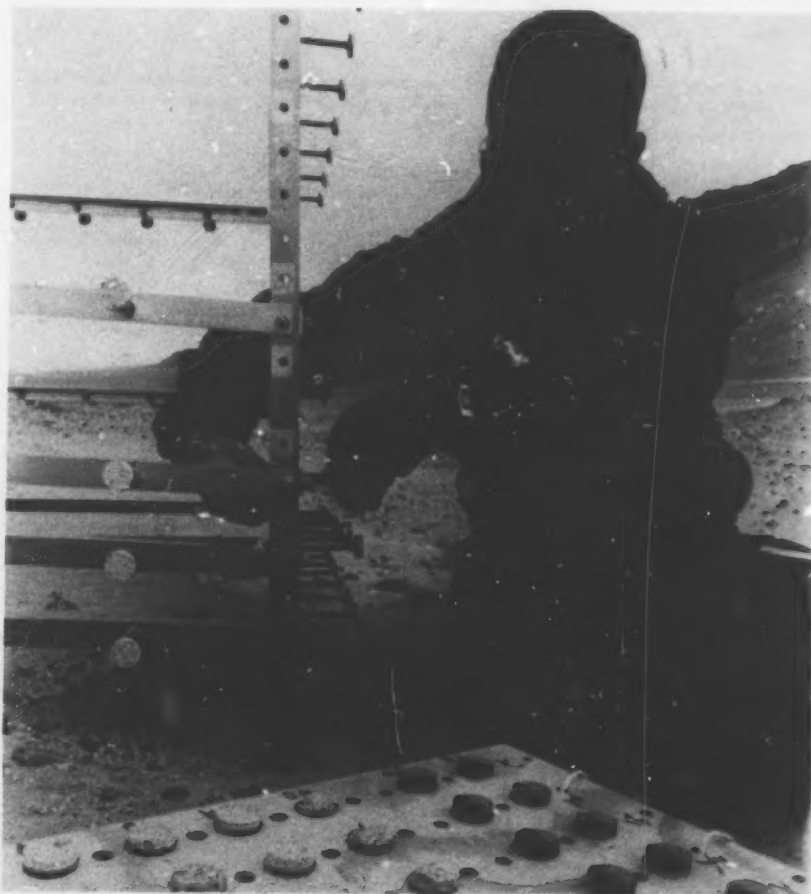
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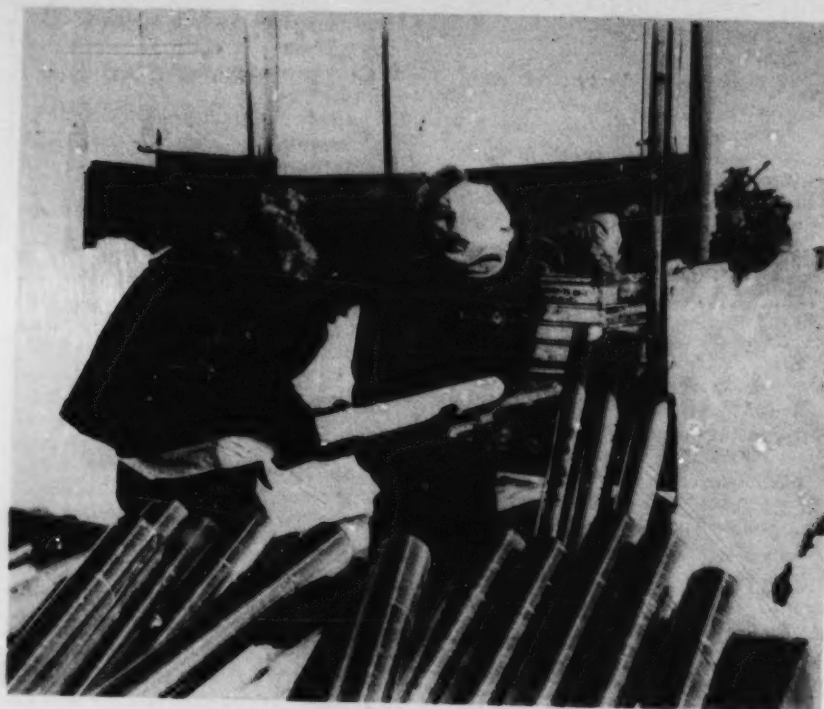
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NSF photo by Ann Hawthorne.





U.S. Navy photo (90278-12-78) by Thomas E. McCabe, Jr.

Ice cores from Antarctica are first stored carefully in tubes before shipping them to the United States. Once they are returned to the United States, glaciologists, geologists, meteorologists, and other scientists analyze the cores to obtain information about past earth environments.

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NSF photo by Ann Hawthorne.

At this field camp near the 100-kilometer-long Beardmore Glacier, geologists, glaciologists, and paleontologists studied changes in the antarctic environment during fluctuations of antarctic ice sheets. This photograph was taken while the camp was in construction during the 1984-1985 austral summer.

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Despite near white-out conditions, U.S. personnel continue their work at Williams Field in early 1985. Williams Field, near McMurdo Station, is the U.S. skiway on the Ross Ice Shelf.

NSF photo by Ann Hawthorne.





U. S. Navy photo by Vaughn.

As part of her trip to Antarctica, Karen Prentice worked at Lake Hoare in Taylor Valley (one of southern Victoria Land's ice-free valleys) with a group of biologists from Virginia Polytechnic Institute and University. Here she assists the biologists by collecting water samples.

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ney anyway and informed officials of both governments that they would not need any assistance. Although they planned to be self sufficient, the sinking of the *Southern Quest* forced them to depend on the resources of the U.S. program.

The United States government has chosen to bill the expedition only for the cost of the flight from Antarctica to Christchurch, New Zealand, and not for the costs of the humanitarian rescue in Antarctica.

Southern Quest rescue

While in McMurdo Sound, *Southern Quest* became trapped between two ice floes, which subsequently ruptured the hull on the port side. Between 7 and 10 p.m., the crew attempted to free the ship from the pack ice. By 10 p.m. water had begun

to flood the engine room, and about 2 hours later, a fire broke out in the engine room. The captain notified McMurdo Station that 21 people were abandoning ship with survival equipment and small boats. The 139-foot, ice-strengthened ship sank between 12:15 and 12:30 a.m. on 12 January after the 14 crew members and 7 passengers had reached safety on a nearby ice floe.

Activity at McMurdo Station began immediately after the station personnel had been alerted by the request for assistance that was relayed from Amundsen-Scott South Pole Station. The National Science Foundation (which manages the U.S. Antarctic Program) met with representatives of the Navy, and the Coast Guard, to plan the rescue. After a briefing by the Operations Officer and the Commander of the Naval Support Force Antarctica, who was instructed to take charge of the search and rescue operation, two Coast Guard HH-52 helicopters left McMurdo Station for the last known location of the ship at 76°56'S 167°13'E about 4 miles east of Beaufort Island. The Coast Guard helicopters, which are attached to the icebreaker *Polar Star*, were used because Navy UH-1N helicopters used by the U.S. Antarctic Program



U.S. Navy photo by Kyne.

Southern Quest survivors arrive at McMurdo Station on 12 January 1986. At the right is one of the U.S. Navy UH-1N helicopters used to fly the survivors from Cape Bird to the U.S. station.

Passengers and crew of the *Southern Quest* arrive on Beaufort Island after being transported by two U.S. Coast Guard HH-52 helicopters from an ice floe near the area where their ship sank.

U.S. Navy photo.





U.S. Navy photo by J. Porbansky.

Survivors receive instructions from U.S. Antarctic Program officials after arriving at McMurdo Station.

are not equipped to fly over open water. At the same time the icebreaker, which was near the ice edge, began to sail towards the stricken ship.

When they reached the site at 1:14 a.m., the pilots reported that the ship was gone and that none of the survivors were injured. At the rescue site the weather was poor. The ceiling was about 300 feet with a visibility of 5 miles. Light snow was falling, and winds were at 15 knots. Because the ship's crew was in danger on the ice floe and the helicopters were low on fuel, the pilots ferried the crew two at a time, along with enough food and fuel to support them for several days, to the nearest land—the southern tip of Beaufort Island.

After all 21 were safely moved to Beaufort Island, the helicopters returned with eight survivors to McMurdo Station to refuel. Accompanied by two Navy UH-1N helicopters that landed at Cape Bird, Ross Island, the Coast Guard helicopters flew back to Beaufort Island. They made two shuttle flights from Beaufort Island to Cape Bird to move the remaining 13 survivors. From there the four helicopters transported the survivors to McMurdo Station. The rescue was completed by 5 a.m. on 12 January 1986.

After the crew and passengers of *Southern Quest* were rescued they were housed, fed, and given medical treatment by the U.S. Antarctic Program at McMurdo Station. The three expedition members (Swan, Mears, and Wood), who walked to the

South Pole from Ross Island and were waiting to be picked up, were cared for at South Pole Station. Later they were transported to McMurdo Station in a U.S. LC-130 airplane to rejoin their expedition.

After arriving at McMurdo Station, the *Southern Quest* survivors were fed and sheltered by the U.S. Antarctic Program until transportation to New Zealand could be arranged. On 19 January 1986 a U.S. ski-equipped Hercules airplane flew 26 members of the expedition from McMurdo Station to Christchurch, New Zealand.

U.S. Navy photo by Caulkins.



On 15 January, 26 of the 29 expeditioners were flown from McMurdo Station to Christchurch, New Zealand, by the U.S. program. Three members of the expedition chose to remain in Antarctica during the 1986 winter.

Since 1900, three other ships have been crushed by the pack ice and have sunk in the waters surrounding Antarctica. In 1903 the Norwegian whaling ship *Antarctic*, which was supporting a Swedish exploration party on Snow Island near the Antarctic Peninsula, was trapped in the pack ice and carried for more than a month by the wind and ice before it sank off the coast of Paulet Island. Twelve years later, in October 1915, the *Endurance*, Ernest Shackleton's ship, was beset and sank a month later.

Today's ice-strengthened ships and icebreakers, as well as advanced technology used to predict ice conditions, have reduced the hazards of ship travel to Antarctica. This technology has not eliminated the need for caution. In December 1981, the West German ice-strengthened research ship *Gotland II* was crushed by the pack ice and sank off the coast of northern Victoria Land. All passengers and crew members successfully abandoned ship with much of their equipment, but even with assistance from the U.S. Antarctic Program the ship could not be saved.

An austral summer field season with the 30th Soviet Antarctic Expedition, 1984-1985

In the spirit of Article III of the Antarctic Treaty, the Soviet Union and the United States traditionally have exchanged scientists. I have been fortunate to participate in three of these exchanges - 1972-1974 (Grew, 1975; 1976), 1976-1977 (Grew, 1977), and 1984-1985.

My program with the 30th Soviet Antarctic Expedition (SAE) was a petrologic and geochronologic study of the Precambrian crystalline rocks near the Amery Ice Shelf (Grew, 1985a). The base of operations was Soyuz, a field camp opened in 1982 at 70°35'S, 68°47'E on the Jetty Peninsula. In contrast to my previous Soviet exchanges, this time I reached Antarctica by air. I joined the SAE in Maputo, Mozambique, for an Ilyushin (IL)-18D flight to Molodezhnaya on 19 November, 1985, and continued on 29 November to Soyuz aboard an IL-14. Return from Soyuz to Molodezhnaya (11 January) and from Molodezhnaya to Maputo (21 February) involved the same airplane.

Transportation

Airplanes play an increasingly important role in transport of Soviet expeditioners to and from Antarctica. A few expeditioners fly the entire distance from the Soviet Union, while others fly as far as Maputo

and then sail to their antarctic destination. The remaining personnel travel the entire distance by ship. During the 1984-1985 season, four round-trip flights (9 hours one way) were made from Maputo to Molodezhnaya in October and November and one in late February; the plane returned to Leningrad for December and January.

The IL-18D is a wheel-equipped, four-engine propeller plane (figure 1). It is especially adapted for long distance (D stands for *dainny* meaning "far") and can carry up to 42 passengers and 6 tons cargo. The landing strip at Mount Vechernyaya near Molodezhnaya is compacted snow. It is maintained year-round (figure 2) but cannot be used for heavy wheeled aircraft like the IL-18D during the warmest time of the austral summer (December-early February). A snow landing strip near Novolazarevskaya Station was successfully tested for the first time in November 1985, by the IL-18D, which flew there from Molodezhnaya.

Ships serving Molodezhnaya in January and February included the ice-reinforced scientific-expeditionary vessel *Mikhail Somov*. Ice-reinforced cargo ship *Pavel Korchagin*, the motor ship *Baikal* for passengers, and the tanker *BAM*. The fast ice broke up near Molodezhnaya soon after

the new year, the earliest break-up observed since the station was opened. Thus *Mikhail Somov* and *Pavel Korchagin* could be moored at the ice barrier 1 kilometer from the station. The tanker arrived on 13 February and remained in open water while kerosene, gasoline, and diesel fuel were pumped to storage tanks on shore.

Soyuz summer station

The summer field base Soyuz presently consists of some 10 prefabricated plywood PDKO huts (description in Grew, 1975) erected on Permian sandstone at the foot of Kamenistaya Platform (see figure in Grew, 1985a). The capacity of this base was considerably expanded this summer. Landing strips for ski-equipped IL-14 two-engine planes have been marked out on the snow, one 300 meters and the other 3 kilometers from the base. Facilities presently available at the base are a dining-room/kitchen building (figure 3), a diesel electrical generating station, radio station, Russian-style sauna *banya*, two overland vehicles *vezdekhody*, (figure 4), and several skimobiles ("Buran" brand). All but one member of the field party flew to Soyuz from Molodezhnaya by IL-14. Most cargo was flown in by MI-8 helicopter from the *Pavel Korchagin*, which was moored in late December to an ice floe in Prydz Bay which is 260 kilometers northeast of Soyuz. This season the base was officially opened 1 December, when national flags of the personnel working at the station were raised. Field activities were conducted for 3 months and were supported by the *vezdekhody* and skimobiles.

The 25 people at Soyuz included six geologists, four geophysicists, two hydrologists, two radiometerists, two geodesists, a cook, a doctor, two radio operators, three driver-mechanics, and two exchange scientists—Professor J. Hofmann of the Bergakademie Freiberg (German Democratic Republic) and myself. The Soviet personnel were largely from the organization Sevmorgeo based in Leningrad, including the research institute Okeangeologiya.

Geological research at Soyuz

Scientific activity included detailed geologic mapping and geochemical sampling, ground gravity, magnetic, and radiometric surveys, and hydrology of such fresh water lakes, as Beaver Lake. The geologists and geophysicists were particularly interested in dikes and breccia pipes of alkaline-ultramafic rocks and a deep-seated fault associated with the continental rift presently occupied by the Amery Ice Shelf and Lambert Glacier (Ravich et al., 1978). Geophysicists surveyed in detail the larger dikes and breccia pipes of the alkaline-ultramafic rocks, which were sampled

Figure 1. Ilyushin - 18D on the Mount Vechernyaya landing strip near Molodezhnaya after arrival from Maputo, November, 1984.

NSF photo by E.S. Grew.





Figure 2. Tractor and plow to level landing strip at Mount Verchernyaya near Molodezhnaya, February, 1985.

NSF photo by E.S. Grew.

extensively for later geochemical and petrologic studies (figure 4).

A deep seismic sounding profile across the Amery Ice Shelf revealed a deep-seated fault zone under the Jetty Peninsula (Ravich et al., 1978; Fedorov et al., 1982). At the present erosional surface, the Jetty Peninsula is underlain largely by Precambrian high-grade metamorphic rocks cut by small bodies of granite and by abundant Phanerozoic mafic dikes (Grew, 1985a). The geodesists staked out profiles, one 21 kilometers long parallel to the meridional fault zone and a second 8 kilometers long across it. Gravity, magnetic, and radiometric measurements, as well as sampling for geologic and geochemical studies, was done at regular intervals along the profiles. In addition, an area 4 kilometers long and about 1 kilometer wide along the meridional profile on Kamenistaya Platform was mapped in detail. Other programs included uranium-lead isotopic age determination of high-grade orthogneisses in cooperation with the Institute of Geochemistry and Physics of Minerals in Kiev, stratigraphy of the coal-bearing Permian sediments south and west of Soyuz, and a geophysical survey of the western boundary fault of the graben filled by these Permian sediments.

Molodezhnaya Station operations and facilities

Molodezhnaya Station, officially called Antarctic Meteorological Center Molodez-

hnaya and the largest of the present seven Soviet year-round stations, has been expanded since I wintered there in 1973. The

wintering party now numbers 126. Buildings erected since 1973 include a synoptic meteorology bureau and working spaces for meteorology and for the radar tracking of meteor trails. A two-story dining-hall/kitchen building is scheduled to be constructed soon. Moreover, there are now facilities at Mount Vechernyaya (10 kilometers east of the main station) for the aviation specialists who maintain the landing strip year-round.

Many of the programs being carried out in 1973 (Grew, 1975) are still operating. These include rocket sounding of the atmosphere (figure 5), meteorological observations, and geophysical observations, for example, of short-period fluctuations of the geomagnetic field, which is conducted in cooperation with Japanese scientists. Exchange scientists from Cuba are studying geophysics and meteorology. Medical researchers presently are investigating the adaptability of the people at the station to the antarctic environment to develop improved procedures to screen applicants for Antarctica. This research is carried out by doctors from the Institute of Experimental Medicine in Moscow.

Cooperative research

After my return from Antarctica, I visited VNI Okeangeologiya in Leningrad 11 to 13 September 1985, where I discussed cooperative work with G.E. Grikurov and V.L. Ivanov. One project, which is underway, is a geochemical and isotopic study of post-metamorphic granites

Figure 3. Dining hall - kitchen building (consists of two PDKO Huts) at Soyuz, January, 1985.

NSF photo by E.S. Grew.



and pegmatites from the Jetty Peninsula in which J. Hofmann (Freiberg), W.I. Manton (University of Texas, Dallas), and I are participating. A second project, which depends on the suitability of samples, is an isotopic study of ultramafic xenoliths from the alkaline-ultramafic breccia pipes. This study should give some information concerning the Earth's mantle underlying the rift in this area.

My work with SAE is an example of the cooperation that is possible between Soviet, American, and German (Democratic Republic) scientists in Antarctica. This cooperation has extended beyond Antarctica to Europe in my case. Recently, I was invited to do field work at the classic Waldheim kornepine locality in the Saxony granulite complex, which crops out near Freiberg in the German Democratic Republic (Grew, 1985b and in press).

I am grateful to all the expedition members whose hospitality and assistance assured the success of my field program in Antarctica this season, particularly, J. Hofmann; L.V. Fedorov, who was in charge of Soyuz; L.V. Bulatov, chief of Molodez-

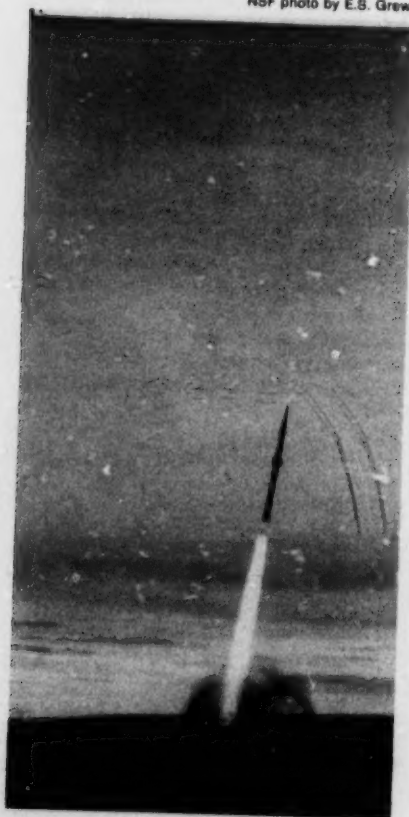


Figure 4. Vezdekhod (overland vehicle) and geologists sampling alkaline ultramafic pipe near Soyuz, January, 1985.

NSF photo by E.S. Grew.

Figure 5. Rocket launch at Molodezhnaya, February 1985.

NSF photo by E.S. Grew.



hnaya; and D.D. Maksutov, chief of the 30th SAE (summer operations). I also thank G.E. Grikurov for his general assistance. I hope that my participation in the SAE will lead to more exchanges of geologists and other scientists between the Soviet Union and the United States and that Antarctica will continue to serve as an example of International cooperation in science.

This research was supported by National Science Foundation grant DPP 84-14014 to the University of Maine, Orono.

—E.S. Grew, Department of Geological Sciences, University of Maine, Orono, Maine 04469.

References

- Fedorov, L.V., G.E. Grikurov, R.G. Kurin and V.N. Masolov, 1982. Crustal structure of the Lambert Glacier area from geophysical data. In: C. Craddock, ed., *Antarctic Geoscience*, p. 931-936, University of Wisconsin, Madison.
- Grew, E.S. 1975. With the Soviets in Antarctica, 1972-1974. *Antarctic Journal of the U.S.*, 10(1), 1-8.
- Grew, E.S. 1976. Geological studies with the Soviet Antarctic Expedition in 1972-1974 (O geologicheskikh issledovaniyakh v Sovetskoy antarkticheskoy ekspeditsii v 1972-1974 gg). *Information Bulletin of the Soviet Antarctic Expedition*, 93, 27-29.
- Grew, E.S. 1977. With the Soviets in Antarctica, austral summer 1976-1977. *Antarctic Journal of the U.S.*, 12(4), 86-88.
- Grew, E.S. 1985a. Field studies on the Jetty Peninsula (Amery Ice Shelf area) with the Soviet 30th Antarctic Expedition. *Antarctic Journal of the U.S.*, 20(5).
- Grew, E.S. 1985b. Petrogenesis of kornepine at the classic locality of Waldheim, German Democratic Republic. *Geological Society of America, Abstracts with Programs*, 17:598 (abstract).
- Grew, E.S. In press. Petrogenesis of kornepine at Waldheim (Sachs.), German Democratic Republic: *Zeitschrift für geologische Wissenschaften* (Berlin).
- Ravich, M.G., D.S. Solov'yev, and L.V. Fedorov. 1978. Geological structure of Mac. Robertson Land (East Antarctica). Leningrad, Gidrometeoizdat (in Russian).

Scientists gather in Ohio to discuss Gondwana

The Sixth Gondwana Symposium, held 18 to 23 August 1985 in Columbus, Ohio, at the Institute of Polar Studies was the first to be conducted outside the countries that once constituted the supercontinent. The symposium drew 151 participants from 19 countries. The largest contingent was from the United States (84); India (14), West Germany (10) and the United Kingdom (10) also were well represented. In this report we have chosen to focus on antarctic papers presented at the symposium. Although they are not recognized here, many excellent papers not related to antarctic topics also were presented.

The meeting opened with a general session on aspects of the reconstruction of Gondwana. Problems remain with the margins of the supercontinent, both in the Tethyan and Pacific regions, but the basic framework is well established. Computer modelling of the break up of Gondwana has provided a more detailed framework for understanding the tectonic history and paleo-oceanographic evolution of the emerging seaways. During this session, participants also discussed the evolution of the continental margin in the Weddell Sea sector.

The second day included concurrent sessions in paleontology and physical geology. During the morning paleontology session, the geologists discussed vertebrate fossils including the affinities and paleogeographic implications of Devonian fish, affinities of fossil fish from Madagascar, distribution of *Mesosaurus* in the Karoo and Parana basins, the evolution of trematosaurs, and Triassic reptiles from India. A series of papers on the silicified peat from the southern Marshall Mountain near the head of the Beardmore Glacier was presented in the afternoon paleobotany session. This formation is yielding significant new data on the anatomy, and morphology of the glossopterid flora and associated fungi.

The physical geology sessions (concurrent with paleontology) dealt with West Antarctica and the Ross Sea sector. Several people presented papers on the results of the United States-United Kingdom west antarctic tectonics project. The most surprising result reported was the new paleomagnetic data for the Ellsworth Mountains. These data suggest that the mountains rotated 20° counterclockwise and place-

ment next to the Falkland Plateau region rather than the 90° clockwise movement reported not so long ago. West Antarctica continues to be a research focus because of the implications for crustal evolution and rearrangement of Gondwana plate margin.

Among the Ross Sea presentations were two papers on geophysical results from the 1983-1984 U.S. Geological Survey (USGS) cruises in antarctic waters. In the first paper, the Victoria Land basin was shown to have a much thicker (approximately 15 kilometers) and probably much older stratigraphic section than thought previously. The other paper tentatively identified Beacon Supergroup strata and associated sills beneath the Wilkes Coast continental margin. Two papers also presented data on crustal structure, including estimates of depth to the Moho.

On the third morning a single session was devoted to the stratigraphy, structure, and sedimentology of Gondwana sequences. The appropriateness of the term Gondwana Sequence for rocks of Late Paleozoic to early Mesozoic age was questioned. The Permian and Triassic paleogeographies of Tasmania and the adjacent sector of Antarctica were clarified. Working groups met during the afternoon.

The session on the fourth morning focused on upper Paleozoic glacial deposits. These papers mainly were on deposits in India and southern Africa. During the afternoon session invertebrate paleontology was discussed. The focus was on sequences and fossils from the margins of Gondwana and biogeographic relations. In the concurrent session on the geology of northern Victoria Land a series of papers were presented on this complex area. It is now clear that a suture zone is located somewhere in the region of the Bowers Trough and that at least the Robertson Bay Group represents a block accreted to Antarctica sometime in the middle to late Paleozoic.

The Gondwana plate margin was the topic for discussion on the final day. Most of the papers were concerned with the South America-Antarctic Peninsula sector and the documentation of melanges and accretionary complexes that range from Early Paleozoic to Late Paleozoic-Early Mesozoic in age.

During the week the Gondwana Subcommittee and its various working groups met, as did the Scientific Committee on Antarctic Research (SCAR) Working Group on Geology, and IGCP Project 203

on the Permo-Triassic boundary. The SCAR Working Group met informally, because only four official delegates attended the symposium. Nevertheless this meeting, which followed a workshop on antarctic geophysics and crustal structure, was productive. The workshop, which was attended by 30 symposium participants, reviewed the various geophysical techniques and their application to problems of crustal structure in Antarctica. Participants agreed that a major new initiative is needed in this area. The SCAR Working Group discussed this proposed research initiative, as well as other matters. In its report to the Working Group Secretary, working group delegates recommended that the official meeting scheduled for SCAR XIX in June 1986 discuss establishing two groups of specialists—one on antarctic crustal structure and the other on late Cenozoic biostratigraphy and paleoclimate.

The Gondwana Subcommittee confirmed Dr. J. M. Dickins (Australia) as chairman and Dr. A. C. Rocha-Campos (Brazil) as vice chairman and appointed two additional vice chairmen, Dr. L. Belletan (France) and Dr. Yang Z. (China). The next symposium is scheduled tentatively to be held in Brazil in 1988 and the following one in Madagascar in 1990.

The American Geophysical Union will publish the Symposium proceedings sometime during the 1986 summer. Of the 105 papers presented, more than 40 percent were concerned with Antarctica or antarctic-related problems. If this proportion is maintained, the volume should be of interest to all antarctic earth scientists.

Field trips offered in conjunction with the symposium included the stratigraphy and structure of the southern Appalachians, the Carboniferous of northeastern Kentucky, and the Proterozoic and Pleistocene glacial deposits of northern Ohio and southern Ontario. One-day field trips near central Ohio also were offered.

This symposium and the preparation of the proceedings have been partially supported by a National Science Foundation grant (EAR 84-07780) jointly funded by the Divisions of Polar Programs and Earth Sciences to Ohio State University.

—David H. Elliot and James W. Collinson, Institute of Polar Studies and Department of Geology and Mineralogy, Ohio State University, Columbus, Ohio 43210.

Girl Scouts visit Antarctica

In Taylor Valley, Karen Prentice chips ice from a hole used by divers working in Lake Hoare.

U.S. Navy photo by Vaughn.



U.S. Navy photo by Porbansky.

During the 1985-1986 austral summer, two Girl Scouts, Karen Prentice (alternate) and Robin Moyle (selectee) participated in the U.S. Antarctic Program. These two young women were selected to participate in the antarctic program by the Girl Scouts of the United States after a national competition. In this photograph Karen (left) and Robin (right) stand near the Richard Byrd memorial at McMurdo Station.



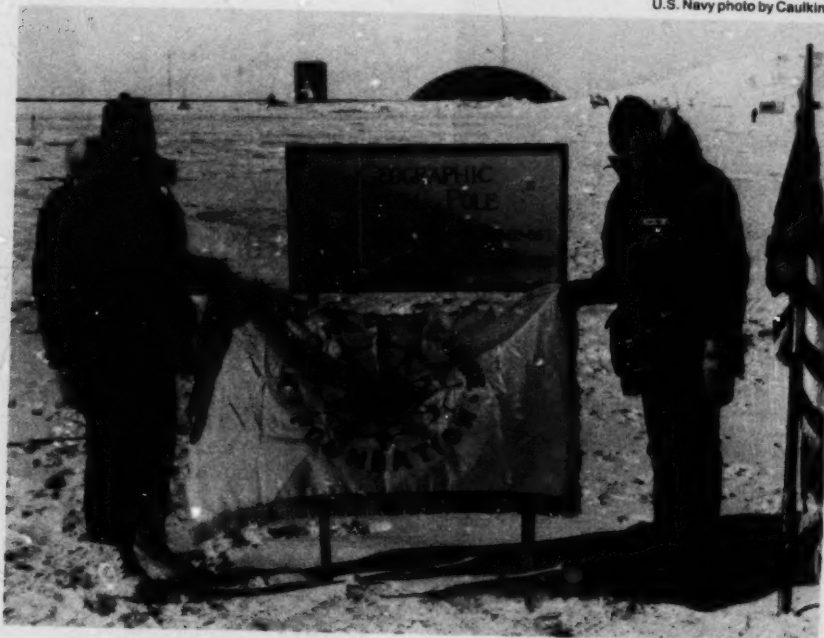
Two emperor penguins watch Girl Scout Robin Moyle at the sea-ice edge.

U.S. Navy photo by Caulkins.



Robin Moyle and NSF geologist Anton Inderbitzen display the National Science Foundation flag at Amundsen-Scott South Pole Station. The geodesic dome, which houses the buildings at the U.S. station, and "skylab" can be seen in the background.

U.S. Navy photo by Caulkins.



Foundation awards of funds for antarctic projects, 1 October to 31 December 1985.

Following is a list of National Science Foundation antarctic awards made from 1 October to 31 December 1985. Each item contains the name of the principal investigator or project manager, his or her institution, a shortened title of the project, the award number, and the amount awarded.

If an investigator received a joint award from more than one Foundation program, the antarctic program funds are listed first, and the total amount of the award is listed in parentheses. Awards initiated by the Division of Polar Programs contain the prefix DPP.

Biology and medicine

Ainley, David G. Point Reyes Bird Observatory, Stinson Beach, California. Antarctic marine ecosystem research at the ice-edge zone. (AMERIEZ): Distribution of sea birds. DPP 84-19894. \$72,619.

Bengtson, John L. Point Reyes Bird Observatory, Stinson Beach, California. Antarctic marine ecosystem research at the ice-edge zone (AMERIEZ): Feeding ecology of Pinnipeds. DPP 84-20851. \$50,000.

Olson, Charles E. University of Michigan, Ann Arbor, Michigan. Measurements of penguin populations at rookeries using thematic mapper satellite data. DPP 85-07483. \$60,100.

At Amundsen-Scott South Pole Station Robin Moyle helps meteorologists with daily weather readings by releasing an instrumented weather balloon.

U.S. Navy photo by Caulkins.



Trivelpiece, Wayne Z. Point Reyes Bird Observatory, Stinson Beach, California. Pygoscelid penguin population studies. DPP 83-14667. \$13,882.

Yen, Jeannette. University of Hawaii-Manoa, Honolulu, Hawaii. Predatory feeding ecology of *Euchaeta antarctica*, a marine planktonic copepod. DPP 84-15395. \$25,766.

Zapol, Warren M. Massachusetts General Hospital, Boston, Massachusetts. Physiological and ecological studies of free-ranging seals. DPP 84-00042. \$153,287.

Earth sciences

Kamb, Barclay. California Institute of Technology, Pasadena, California. Field and laboratory studies of geologic case hardening in the ice-free valleys of southern Victoria Land. DPP 82-15121. \$5,202.

Glaciology

Bentley, Charles R. University of Wisconsin, Madison, Wisconsin. Continuation of glaciogeophysical survey of the interior Ross embayment. DPP 84-12404. \$325,025.

Meteorology

Wendler, Gerd. University of Alaska, Geophysical Institute, Fairbanks, Alaska. Katabatic winds in eastern Antarctica. DPP 84-13367. \$149,600.

Ocean sciences

DeMaster, David J. North Carolina State University, Raleigh, North Carolina. Chronometry and geochemistry of siliceous sediments. DPP 85-12514. \$62,841.

LaBrecque, John L. Columbia University, Palisades, New York. Aerogeophysical survey of the basins surrounding the Antarctic Peninsula. DPP 85-17635. \$343,343.

Smethie, William M. Columbia University, Palisades, New York. *Polarstern* winter-86 expedition: krypton-85 as deep water mass tracers. DPP 85-01886. \$33,602.



U.S. Navy photo (80295-12-78) by Thomas E. McCabe, Jr. At Dome C in East Antarctica, French, Swiss, and U.S. glaciologists drill ice cores from the antarctic ice sheet in 1978.

Takahashi, Taro. Columbia University, Palisades, New York. Investigation of carbon chemistry in the Weddell Sea area during the 1986 winter expedition of the *Polarstern*. DPP 85-04252. \$137,557.

Support and services

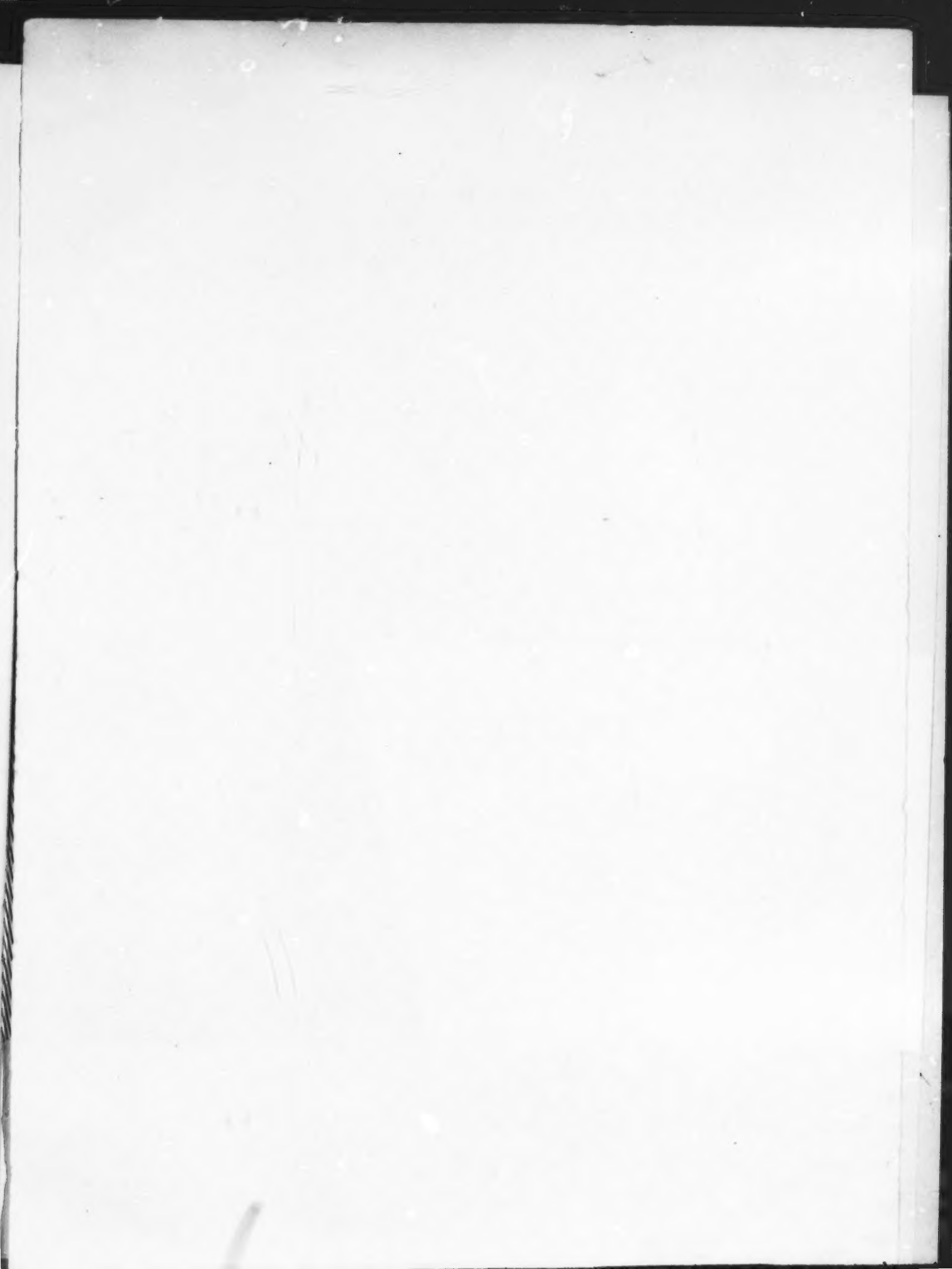
Becker, Robert A. ITT/Antarctic Services, Inc. Paramus, New Jersey. Specialized support of the United States Antarctic Research Program. DPP 80-03801. \$10,000,000.

Fleming, Henry S. Naval Research Laboratory, Washington, D.C. Aerogeophysical study of the basins surrounding the Antarctic Peninsula. DPP 86-00663. \$401,500.

Haas, Wilbur M. Michigan Technological University, Houghton, Michigan. Development of methods for design of snow roads and airstrips. DPP 85-17148. \$26,244.

Hinners, Noel W. National Aeronautics and Space Administration-Goddard Space Flight Center, Greenbelt, Maryland. Support of the South Pole satellite data link system. DPP 86-02101. \$25,000.

Landrum, Betty J. Smithsonian Institution, Washington, D.C. Recording of data and sorting of collections from polar regions. DPP 74-13988. \$109,992 (\$169,992).



Weather at U.S. stations

Feature	November 1985				December 1985				January 1986			
	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole
Average temperature (°C)	-10.7	2.5	-17.0	-40.3	-4.4	3.7	-13.6	-30.8	-3.1	5.2	-13.4	-25.9
Temperature maximum (°C) (date)	-2.0 (26)	8.8 (12)	-4.0 (16)	-30.0 (7)	-3.1 (13)	11.1 (24)	-3.2 (27)	-23.2 (31)	-5.5 (18)	8.7 (4)	-1.5 (12)	-19.0 (3)
Temperature minimum (°C) (date)	-20.8 (10)	2.5 (5)	-27.0 (14)	-47.5 (10)	-12.0 (2)	-1.0 (7)	-22.7 (3)	-36.9 (2)	-11.2 (29)	-3.0 (14)	-24.8 (22)	-36.9 (31)
Average station pressure (mb)	972.5	986.7	855.8	674.3	981.4	979.6	861.2	682.9	989.1	984.1	868.8	691.3
Pressure maximum (mb) (date)	988.9 (8)	1010.0 (1)	861.8 (23)	684.5 (6)	995.2 (29)	997.0 (29)	875.1 (27)	694.9 (31)	998.7 (2)	1002.5 (15)	884.9 (13)	700.6 (13)
Pressure minimum (mb) (date)	962.6 (13)	968.2 (18)	950.4 (18)	662.8 (12)	964.4 (5)	954.2 (16)	846.5 (10)	678.3 (18)	981.0 (28)	966.2 (23)	857.4 (25)	684.1 (31)
Snowfall (mm)	25.4	185.4	---	TRACE	29.2	35.6	---	TRACE	TRACE	3.3	---	TRACE
Prevailing wind direction	065°	330°	170°	070°	115°	240°	156°	360°	085°	180°	110°	360°
Average wind (m/sec)	4.1	6.9	4.0	3.4	4.9	4.0	5.0	3.1	4.2	4.7	4.3	5.7
Fastest wind (m/sec) (date)	19.7 (4) 150°	29.3 (18) 360°	11.6 (27) 030°	13.4 (6) 270°	23.7 (5) 180°	26.3 (9) 060°	21.5 (16) 140°	9.8 (18) 360°	16.5 (12) 070°	19.6 (28) 090°	15.2 (2) 140°	15.4 (11) 360°
Average sky cover	6.6	8/10	6.0	6.9	7.8	0.0	8.6	0.5	6.4	7/10	7.9	0.7
Number clear days	4	7	2	8	0	15	1	12	4	16	7	6
Number partly cloudy days	13	4	4	3	8	6	11	3	8	3	4	12
Number cloudy days	13	20	10	19	23	9	18	16	19	9	20	13
Number days with visibility less than 0.4 km.	0.0	0.0	2	0.4	0.8	0.0	9.0	0.1	1.0	0.0	5.5	0.0

Prepared from information received by teletype from the stations. Locations: McMurdo 77°51'S 166°40'E, Palmer 64°46'S 64°33'W, Amundsen-Scott South Pole 90°S. Elevations: McMurdo sea level, Palmer sea level, Amundsen-Scott South Pole 2835 meters. Siple Station (75°55'S 83°55'W) was closed for the winter in January 1984 and will reopen November 1985. For prior data and daily logs, contact National Climate Center, Asheville, North Carolina 28801-2696 (704/259-0682).

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Advances in antarctic geophysical sciences from the IGY to the present

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Because this is a special issue, the NSF awards list, covering 1 January to 31 March 1986, for antarctic research and support will appear in the September 1986 issue.

Introduction

In the fall of 1985, members of the Polar Research Board, National Academy of Sciences, National Research Council, presented a symposium summarizing scientific accomplishments in the Antarctic since the International Geophysical Year (IGY). The presentations are one component of a much larger evaluation of past accomplishments, present capabilities,

and future antarctic scientific needs that the Polar Research Board is preparing for the National Science Foundation's Division of Polar Programs.

This issue of the *Antarctic Journal* contains written summaries of post-IGY accomplishments in five scientific disciplines: upper atmosphere research, meteorology, physical oceanography, earth sciences, and glaciology. The December

This map shows stations, camps, and other sites that are discussed in the papers in this issue. Currently, the United States operates McMurdo, South Pole, Siple, and Palmer stations.



issue will contain two additional summaries, terrestrial and marine biology, as well as the latest results of this year's Antarctic Marine Ecosystem Research at the Ice Edge Zone (AMERIEZ) Program.

Post-IGY science in each of the five disciplines has consisted of a combination of manned field studies and an ever-increasing number of instrumented observations, made from antarctic ground stations, ships, aircraft, and satellites. In spite of the explosive increase in technology, the human component in the Antarctic (scientists, technicians, and the staff that support these remote operations) is the single most important factor in our success in unraveling the mysteries of Antarctica and the surrounding oceans.

In the earth sciences, improved marine seismic techniques have permitted researchers to study the sea floor and define the composition and thickness of the upper layers of the Earth. Simultaneously, geologists working on terrestrial outcrops have discovered that the antarctic ice sheet may have been significantly smaller within the past few million years.

In glaciology, the most dramatic advance has been the development of radar

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technologies to determine ice thickness and related properties. As technology evolves, these observations may, in the next decade, be made from orbiting polar satellites. Yet, ice coring and the analysis of ice cores collected from drill holes are still the primary techniques that glaciologists use to unlock the record of changes of world climate that is contained in the Antarctic ice.

In meteorology, the development of sophisticated computer systems has permitted scientists to create models that mirror the complexities of atmospheric circulation and to apply these results to defining antarctic meteorology and climatology. These models are predicated on data collected by field meteorologists.

The United States commitment to antarctic science spans much of this

century, and our continuous presence on the continent, beginning with IGY, is approaching its fourth decade. The summaries presented here provide insight

into the scope and content of our scientific programs. Progress has been significant, and our knowledge includes far more than just the tip of the iceberg.

Upper atmosphere research

At the time of the International Geophysical Year (IGY), the geographic distribution of many phenomena occurring in the upper atmosphere* was poorly understood. A major thrust of the research during the IGY was to delineate geomagnetic and ionospheric phenomena from various locations on the antarctic continent (Waynick, 1965).

Data acquired during the 30 years that have elapsed since the IGY have revolutionized our understanding of the physics and chemistry of upper atmosphere phenomena. Much of this revolution was brought about by the advent of scientific spacecraft (both earth-orbiting and earth-escaping), which delineated the morphology of the magnetosphere. This region of space around the Earth is where the terrestrial magnetic and electric fields wholly dominate the transport and motion of charged particles (figure 1).

Upper atmosphere research in the Antarctic has changed dramatically from

the basic exploration emphasized in the IGY to the use of the continent as a platform for active and passive studies of micro- and macro-scale variations in the Earth's magnetosphere (Lanzerotti and Krimigis, 1985). Studies particularly of interest to upper atmosphere researchers are those associated with the internal magnetospheric boundary (known as the plasmapause) and the auroral and polar cap regions.

Geomagnetic field lines threading through the outer regions of the Earth's magnetosphere (figure 1) intercept the ionosphere and the Earth's surface in high-latitude regions. Because of the approximately 12° offset between the Earth's spin axis and the dipole axis, field lines from the inner magnetosphere also can intersect Earth at rather high geographic latitudes at some locations. Indeed, the antarctic continent encompasses a wide range of geomagnetic latitudes, as illustrated in figure 2 for the case of local geomagnetic noon at the geographic South Pole.

The field lines at about geomagnetic latitude 60°S in the region of Siple Station (SI), Halley Bay (HB), and SANAE (SA) pass through the magnetosphere at the equator at a radial distance of approximately 4 Earth radii near the typical position of



Editor: Winifred Reuning

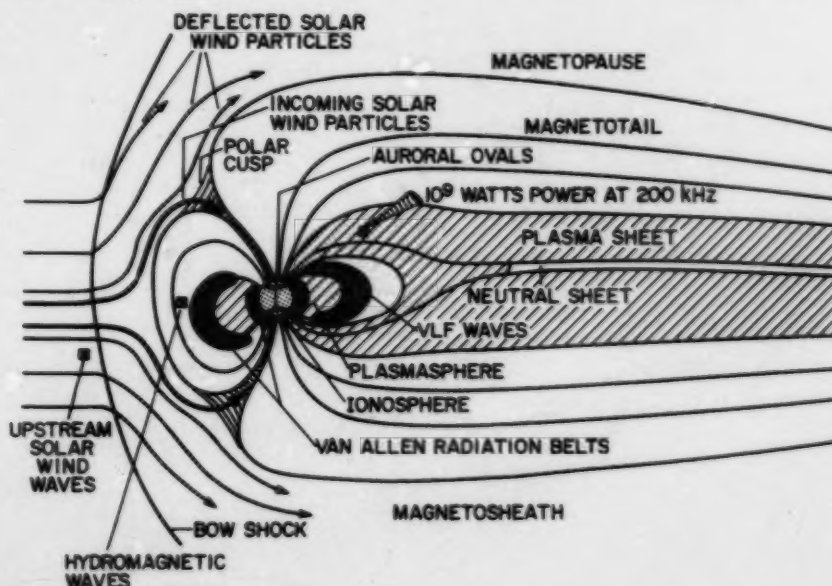
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The Director of the National Science Foundation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this agency. Use of funds for printing this periodical has been approved by the director of the Office of Management and Budget through 31 March 1991.

*In this discussion, the upper atmosphere is defined broadly to cover regions from an altitude of about 30 kilometers upwards as far as the sun.

Figure 1. The magnetosphere of Earth, schematically illustrating a number of important morphological features.





plasmopause. In contrast, stations such as Syowa (SY) and Byrd are in the auroral zone, corresponding to field lines traced to an equatorial altitude of about 6 Earth radii. South Pole Station (SP) is in the magnetospheric cusp region near local geomagnetic noon with field lines tracing close to the magnetosphere boundary. McMurdo (MM) and Vostok (VO) stations are usually deep within the southern magnetosphere polar cap on field lines which are "open" and stretch deeply into the magnetosphere tail. Palmer Station (PA) is normally deep within the plasmasphere.

Magnetic field lines can be traced from one hemisphere to the other through the magnetosphere. Observing locations at opposite ends of a magnetic field line are called "conjugate." The Antarctic has several geographic areas that are connected by magnetic field lines to land regions in the Northern Hemisphere. Presently, the geographic location of Antarctica often is used effectively for conjugate studies in conjunction with simultaneous measurements primarily from Canada, Greenland, and Iceland, as well as on spacecraft. The twin features of the wide geomagnetic coverage of Antarctica and the conjugate relationships of the continent to northern hemisphere sites have been used to optimum advantage in recent years by U.S. upper atmosphere scientists studying the Earth's magnetosphere and ionosphere. Another feature of Antarctica that is important for many investigations is the low ambient noise levels of normal electromagnetic interferences. This feature offers the distinct advantage of high signal-to-noise ratios or greater sensitivity of measurement for many studies.

In recent years, South Pole Station, with its continuous daylight conditions during the austral summer, has been used for solar astronomy, especially for studies of the regular, periodic (minutes to hours) oscillations of the Sun as it transfers heat from its internal thermonuclear source to the surface (Grec et al, 1980; Fossat et al, 1981; Duvall et al, 1986). Likewise, interest has begun recently to center on the exploitation of the high-altitude, low-humidity conditions at the South Pole to investigate the potentials of other astronomical research at that location. Clearly, for contemporary upper atmosphere, solar, and astronomical research, the ideal location of Antarctica is the primary motivation rather than basic understanding of the conditions of the continent itself.

Much of antarctic upper atmosphere research following the IGY to the mid-1970's was summarized in the volume edited by Lanzerotti and Park (1978). A major international program in magnetospheric research during the 1976-1980 interval was the International Mag-

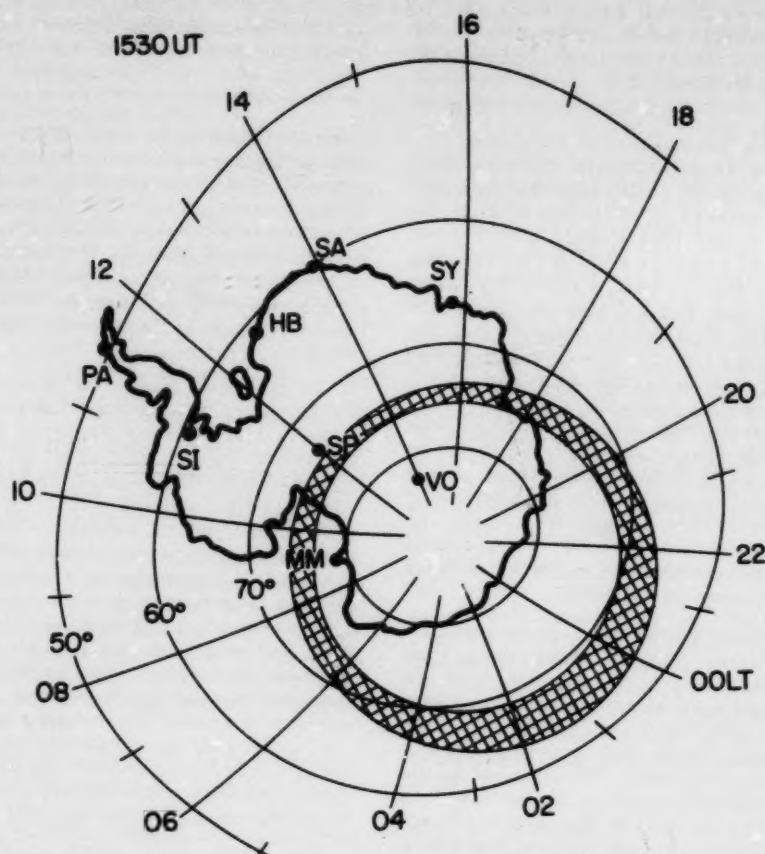


Figure 2. Geomagnetic coordinate system superimposed on the antarctic continent at local magnetic noon at South Pole. The nominal auroral oval is indicated at this local time. The several antarctic stations indicated by two letter codes are identified in the text.

netospheric Study (IMS), in which antarctic studies and several conjugate locations played important roles. Summaries of available data from antarctic sites during this program are contained in papers by Rosenberg (1982), Rycroft (1982), and Nagata and Hirasawa (1982) for U.S., European and worldwide, and Japanese observations, respectively. The following briefly summarizes some of the most recent studies that U.S. researchers have conducted by making use of the excellent locations and facilities afforded by the U.S. Antarctic Program. The included references are only representative of a much broader literature that exists and that can be obtained by contacting the various individual research groups.

Wave-particle interactions

Trapped particles in the magnetosphere can interact with the various plasma waves that also exist there. These wave-particle interactions can cause trapped particles to be lost from the magnetosphere. The particles impact the ionosphere and produce x-ray and optical emissions, as well as perturb the magnetic and electric fields at and below the site of impact.

Antarctic-based research has significantly contributed to the understanding of wave-induced particle precipitation from the Earth's magnetosphere. Natural plasma waves in the extremely-low-frequency/very-low-frequency (ELF/VLF) bands (approximately 100 to 5,000 hertz) were, for the first time, observed simultaneously with X-rays (Rosenberg et al, 1971, 1981; Foster and Rosenberg, 1976), photoemissions, and D-region ionization enhancements produced by the precipitating particles (Helliwell et al, 1980).

The discovery of the "Trimp effect" in antarctic data acquired in the mid-1960's provided extensive evidence that whistler waves, which are generated by lightning signals that then propagate in the magnetosphere, can trigger the precipitation of detectable fluxes of greater than 40 kiloelectronvolts electrons (Helliwell et al, 1973). These electrons cause perturbations (the "Trimp effect") of the phase and amplitude of manmade VLF-waves (most often used as navigation signals) propagating below the ionosphere and reflect off it. The whistler-induced perturbation of these sub-ionospheric ELF/VLF signals is now recognized as a well

established technique for studying the physics of the wave-induced scattering process, as well as the ionospheric effects of impulsive particle precipitation (Inan et al, 1985).

In the Antarctic and in the northern hemisphere conjugate regions, upper atmosphere scientists now are studying fundamental questions about what role waves, which are initiated by lightning and thunderstorms, have in the loss of radiation belt particles at mid to low latitudes. Recent findings include the discovery of perturbations in manmade signals with frequencies as high as 800 kilohertz (Carpenter et al, 1984), perturbations in the signal phase with implications for global ELF/VLF navigation (Inan et al, 1985), and discovery of "Trimp effects" due to whistlers and other natural waves that propagate outside the plasmasphere (beyond an equatorial distance of about 4 Earth radii; see figure 1) (Carpenter et al, 1985).

The experimental results from antarctic research on wave-induced precipitation effects have helped to guide theoretical research and have advanced the capabilities not only for modeling these effects but also for comparing data and theory (Tolstoy et al, 1982, 1986). This observational and theoretical research is applicable to magnetospheric physics as a whole, not just to the antarctic-observed phenomena.

Antarctic research also has been important for related experiments in wave-particle studies. Examples include the successful efforts to stimulate wave-particle interactions artificially with ground-based transmitters (Helliwell and Katsufakis, 1978) and the SEEP experiment, a satellite project that studied in some detail lightning-generated whistler waves and that made the first direct observations of electrons precipitated by manmade waves (Imhof et al, 1983). These experiments are discussed below.

Related wave-particle interaction studies include the detailed measurements on the ground of magnetic pulsations produced by impulsive electron precipitation (e.g., Arnoldy et al, 1982; Engebretson et al, 1983, 1984; Lanzerotti and Rosenberg, 1983). The incident electrons produce transient variations in the conductivity of the ionosphere, which in turn lead to the observed geomagnetic variations. These studies provided insight into how frequently the phenomena occur and on how the phenomena could be used to deduce important parameters of the ionosphere where the electrons stop.

Rocket payloads have been used at Siple Station by U.S. investigators to study directly the electrons involved in wave-particle interactions and X-rays (Benbrook et al, 1983; Roederer et al, 1985; Sheldon et

al, 1985). These investigative tools have added important capabilities to antarctic research and have contributed to understanding magnetosphere processes.

Particles impacting the upper atmosphere also produce variations in the optical emissions where the atoms are excited and return to their ground states. The most important results associated with optical studies followed from the identification of the unique character of dayside aurora and its association with the magnetospheric cusp (see figure 2) (Eather and Mende, 1971).

The geographic South Pole is one of the best ground-based locations from which to study dayside aurora. Studies at this station since the early 1970's have led to a clear description of dayside aurora and its differences from nightside aurora (Eather, 1984). In addition, and more importantly, studies of the movements of dayside aurora as a function of geomagnetic latitude and the close association of these movements with geomagnetic disturbances (substorms) have had important implications for magnetospheric physics. These include the fundamental question of whether the substorm is directly driven by the solar wind or by a storage/release process, in which energy from the solar wind is first stored for a lengthy interval before being released to cause the substorm.

Active VLF experiments

The antarctic ice sheet is an ideal location for establishing long antennas to monitor passive signals and to be connected to powerful transmitters for broadcasting signals into the ionosphere and magnetosphere (Helliwell and Katsufakis, 1978). At Siple Station controlled experiments using a 42-kilometer-long dipole antenna that transmits coherent VLF signals (about 2 to 5 kilohertz) have revealed the existence of a highly nonlinear, narrow-band wave-growth process. Called the "coherent wave instability" (CWI), this mechanism appears to be based on doppler-shifted, cyclotron wave resonance between the input waves and the counter-streaming electrons near the equatorial plane of the magnetic field line along which the wave is propagating.

For input signals exceeding a certain threshold, the CWI causes coherent waves to grow at large exponential rates of 25 to 240 decibels per second (Helliwell et al, 1980). Following saturation, typically at 20 to 40 decibels above the input signal level, narrowband wave emissions are usually spontaneously triggered, lasting a few tenths of a second and rising or falling in frequency by several hundred hertz or more according to the input frequency. These triggered emission signals may be suppressed or entrained by other injected signals from ground VLF transmitters (such

as Navy navigation satellite transmitters) or northern hemisphere power grids.

Two-frequency input signals from the Siple transmitter can produce strong sidebands up to 100 hertz from the carriers. Noise simulation experiments show that the elements of the noise can coalesce into longer, quasi-coherent wave trains (Helliwell et al, 1986b). These two results suggest that hiss and chorus, two of the most important wave emissions from natural magnetospheric plasma, may simply be different aspects of the CWI.

The large gains found in these artificial wave-injection experiments can account in a natural way for several recently discovered connections between naturally-occurring VLF waves and precipitating electrons. For example, investigators have demonstrated that such natural VLF events produce X-rays, light emissions, and perturbation of the intensity and phase of waves reflected from the ionosphere. Recent discoveries of similar wave phenomena in the magnetosphere of Jupiter suggest that this wave-particle interaction process may be a prominent feature of most astrophysical plasmas.

Artificial wave transmissions from Siple Station have revealed a new type of plasma instability that affects coherent VLF signals propagating at low altitudes in the subauroral ionosphere. The effect involves energetic particle precipitation from the magnetosphere with the resultant creation and maintenance of ionospheric irregularities, the scattering and amplification of electromagnetic and electrostatic waves, and the enhanced scattering of energetic electrons (Bell and Katsufakis, 1985). Joint international experiments involving VLF transmissions from Siple Station and measurements from Canadian, Japanese, French, and Soviet satellites have revealed important new features of VLF wave-particle interactions both in the ionosphere and in the high-altitude magnetosphere (e.g., Bell et al, 1983; Kimura et al, 1983).

Besides using satellites to monitor VLF broadcasts from Siple Station, scientists have launched sounding rockets from that station to study in detail the propagation of VLF signals across the neutral atmosphere-ionosphere boundary. The instruments on the sounding rockets measured the transmission efficiency of the Siple transmitter into the ionosphere to be about 0.0001 (Kintner et al, 1983). Because all previous VLF signal diagnostics were ground-based, the sounding rocket receivers provided a "truth test" of the assumption that the ground-based results represented the signal in the overhead ionosphere. On some occasions scientists observed significant differences between rocket and ground measurements; natural whistler waves and nonlinear effects on

the Siple transmissions observed by the sounding rockets were not observed by the ground-based VLF receivers. These differences were most likely caused by sharp density gradients in ionization in the ionosphere E-region which were consistently observed to reflect downward-propagating natural waves from the plasmasphere back into the magnetosphere (Brittain et al, 1983).

Structure of the magnetosphere

Data acquired in the Antarctic was key in defining the plasmasphere (figure 1), the region of cold plasma that approximately co-rotates with the Earth as the Earth turns (Carpenter, 1963). Inside the plasmasphere, the plasma densities can be several thousand ions and electrons per cubic centimeter whereas outside the densities can be much less—1 to 10 per cubic centimeter or less. The transition region (the plasmopause) can be quite sharp, less than 0.5 Earth radius at the equator on occasion.

Naturally-occurring VLF signals measured at Eights, Byrd, Siple and Palmer stations have revealed many aspects of the plasmopause and plasmasphere (Carpenter and Park, 1973). On the average, the plasmopause is fixed in sun-earth coordinates with a dawn-dusk asymmetry involving a dusk-side bulge. The equatorial radius of the plasmopause roughly varies inversely with the level of magnetic disturbance.

Antarctic research has also provided important results on many dynamic features of the magnetosphere. Decreases in the nightside plasmasphere radius and sunward surges of the dusk-side bulge have been measured during substorms. The multi-day refilling time of depleted regions of plasma following magnetic storms was found in antarctic data and led to overall descriptions of a cyclic plasmaspheric process of fast plasma loss and slow replenishment from the ionosphere (Carpenter and Park, 1973). Features of the ionosphere near the plasmopause have been studied by using ionosond techniques (Berkey and Jarvis, 1985).

Several important propagation features of whistler waves in the magnetosphere plasma were described from antarctic data. These include

- the half-gyrofrequency cutoff of whistler propagation in magnetospheric plasma ducts
- the triggering action of whistlers in producing bursts of waves that scatter particles into the ionosphere (Rosenberg et al, 1971)
- the coupling between nearby whistler paths at the time of reflection from the ionosphere (Smith and Carpenter, 1982)

- amplification of whistlers in the magnetosphere that depends on their frequency-time characteristics (Carpenter et al, 1986).

Hydromagnetic waves

Data from antarctic stations (particularly Siple Station) and the Siple conjugate area have helped to define the field-line resonance nature of hydromagnetic waves with frequencies in the range of approximately 0.05 to 0.001 hertz (Lanzerotti, 1978). In particular, scientists have found that the density gradient at the plasmopause significantly influences how hydromagnetic waves produced by the solar wind are coupled to specific geomagnetic field lines and why this causes them to resonate like a guitar string (e.g., Chen and Hasegawa, 1974; Southwood, 1974). Such waves can cause considerable energy transfer to the ionosphere under certain conditions.

X-ray and extreme ultraviolet (EUV) radiation from solar flares produce sudden conductivity changes in the ionosphere. Siple data and data from the conjugate area show that such conductivity changes can apparently launch hydromagnetic waves into the magnetosphere (Rosenberg et al, 1981).

Waves in the range of 10 to 0.1 hertz are often produced by the spiraling of protons and helium ions around the geomagnetic field lines. Measurements of magnetic field changes in this frequency range at Siple Station and in the conjugate area have shown that the polarizations of these waves apparently identify the location of wave generation in the magnetosphere (Arnoldy et al, 1979).

Cosmic rays

U.S. studies in the Antarctic of solar and galactic cosmic rays have concentrated on measurements at McMurdo and South Pole stations. The asymptotic cone of acceptance for cosmic rays at McMurdo Station is nearly perpendicular to the ecliptic plane. Measurements at McMurdo, in conjunction with those from Thule, Greenland, (almost perpendicular to the north ecliptic plane) are important for determining north-south anisotropies of cosmic-ray fluxes. The altitude of South Pole (with an asymptotic cone of acceptance approximately in the ecliptic plane because of the tilt of the geomagnetic dipole axis) means that the cosmic-ray counting rates are higher and the energies detected directly are lower than at a comparable station, for example, on the coast.

A number of specific recent discoveries relate to measurements of the north-south (n-s) cosmic ray asymmetries. These include

- measurements of transient (Pomerantz and Duggal, 1972) and long-term (Pomerantz et al, 1982) n-s anisotropies

- the study of the solar cycle variation of the n-s asymmetry and its implications for the galactic cosmic-ray radial gradient in the solar system (Bieber and Pomerantz, 1986)

- two classes of periodicities in cosmic-ray anisotropy related to solar rotation (Jacklyn et al, 1984)

- cosmic-ray intensity waves extending over the energy range from 1 to 200 gigaelectronvolts, (Duggal et al, 1981).

The data also have been used to analyze and understand the effects of various types of interplanetary disturbances (produced by solar activity) on cosmic-ray fluxes (e.g., Duggal et al, 1983). Finally, observations of relativistic solar cosmic rays have provided new insights into the propagation of energetic solar particles in the corona and in interplanetary space (e.g., Bieber et al, 1986).

Analytical studies of these and numerous other effects, which manifest themselves as temporal variations of the antarctic cosmic-ray intensity, coupled with theoretical investigations of physical processes that can produce them have provided new insights into the large-scale structure of the solar system and its control by the sun, as well as fundamental aspects of solar physics.

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—Louis J. Lanzerotti, AT&T Bell Laboratories, Murray Hill, New Jersey 07974.

References

- Arnoldy, R.L., P.B. Lewis, Jr., and L.J. Cahill, Jr. 1979. Polarizations of Pc1 and IPDP pulsations connected with particle precipitation. *Journal of Geophysical Research*, 84, 7091.
- Arnoldy, R.L., K. Dragoon, L.J. Cahill, Jr., S.B. Mende, and T.J. Rosenberg. 1982. Detailed correlations of magnetic field and riometer observations at L=4.2 with pulsating aurora. *Journal of Geophysical Research*, 87, 10449.
- Bell, R.F., J.S. Inan, I. Kimura, H. Matsumoto, T. Mukai, and K. Hashimoto. 1983. EXOS-B/Siple VLF wave-article interaction experiments: 2. Transmitter signals and associated emissions. *Journal of Geophysical Research*, 88, 295.
- Bell, T.F., and J.P. Kasprakis. 1985. A new type of VLF emission triggered at low altitude in the subauroral region

- by Siple Station VLF transmitter signals. *Journal of Geophysical Research*, 90(1), 183.
- Benbrook, J.R., E.A. Bering, H. Leverenz, J.L. Roeder, and W.R. Sheldon. 1983. Quiet-time electron precipitation at L=4 in the South Atlantic Anomaly. *Journal of Geophysical Research*, 88, 189.
- Berkey, R.T., and M.J. Jarvis. 1985. Observations of the mid-latitude ionospheric trough from Antarctica. AGARD Conference Proceedings, 382, 4.6-1.
- Bieber, J.W. and M.A. Pomerantz. In press. Solar cycle variation of cosmic ray north-south anisotropy and radial gradient. *Astrophysical Journal*.
- Bieber, J.W., P.A. Evenson, and M.A. Pomerantz. In press. Focusing anisotropy of solar cosmic rays. *Journal of Geophysical Research*.
- Brittain, P., P.M. Kintner, M.C. Kelly, J.C. Siren, and D.L. Carpenter. 1983. Standing wave patterns in VLF hiss. *Journal of Geophysical Research*, 88, 7059.
- Carpenter, D.L. 1963. Whistler evidence of a 'knee' in the magnetospheric ionization density profile. *Journal of Geophysical Research*, 68, 1675.
- Carpenter, D.L. 1968. Ducted whistler-mode propagation in the magnetosphere; a half-gyrofrequency upper intensity cutoff and some associated wave growth phenomena. *Journal of Geophysical Research*, 73(9), 2919.
- Carpenter, D.L., and C.G. Park. 1973. On what ionospheric workers should know about the plasmopause-plasmasphere. *Review of Geophysics and Space Physics*, 11, 133.
- Carpenter, D.L., U.S. Inan, M.L. Trimpi, R.A. Helliwell, and J.P. Katsufakis. 1984. Perturbations of subionospheric LF and MF signals due to whistler-induced electron precipitation bursts. *Journal of Geophysical Research*, 89, 9857.
- Carpenter, D.L., U.S. Inan, E.W. Paschal, and A.J. Smith. 1985. A new VLF method for studying burst precipitation near the plasmopause. *Journal of Geophysical Research*, 90, 4383.
- Carpenter, D.L., D. Sulic, and A.J. Smith. 1986. The third-lap whistler anomaly; possible evidence of df/dt dependent wave amplification. *Journal of Atmospheric and Terrestrial Physics*, 48, 171.
- Chen, L., and A. Hasegawa. 1974. A unified theory of long period micropulsations, I. Steady state approach. *Journal of Geophysical Research*, 79, 1024.
- Duggal, S.P., R.M. Jacklyn, M.A. Pomerantz, and C.H. Tsao. 1981. Cosmic ray intensity waves at high rigidities. *Proceedings of the 17th International Cosmic Ray Conference*, Paris, Volume 10, 179-182.
- Duggal, S.P., M.A. Pomerantz, R.K. Schaefer, and C.H. Tsao. 1983. Cosmic ray modulations related to the interplanetary magnetic field intensity. *Journal of Geophysical Research*, 88, 2973-2981.
- Duvall, Jr., T.L., J.W. Harvey, and M.A. Pomerantz. In press. Latitude and depth variation of solar rotation. *Nature*.
- Eather, R.H. 1984. Dayside auroral dynamics. *Journal of Geophysical Research*, 89, 1695.
- Eather, R.H. 1985. Polar cusp dynamics. *Journal of Geophysical Research*, 90, 1569.
- Eather, R.H., and S.B. Mende. 1971. Airborne observations of auroral precipitation patterns. *Journal of Geophysical Research*, 76, 1746-1755.
- Eather, R.H., S.B. Mende, and E.J. Weber. 1979. Dayside aurora and relevance to substorm current systems and dayside merging. *Journal of Geophysical Research*, 84, 3339.
- Engbreton, M.J., L.J. Cahill, Jr., R.L. Arnoldy, S.B. Mende, and T. J. Rosenberg. 1983. Correlated irregular magnetic pulsations and optical emissions observed at Siple Station, Antarctica. *Journal of Geophysical Research*, 88, 4841.
- Engbreton, M.J., L. J. Cahill, Jr., J.D. Winningham, T.J. Rosenberg, R.L. Arnoldy, N.C. Mayward, M. Sugiura, and J.H. Doolittle. 1986. Relations between morning sector Pi1 pulsation activity and particle and field characteristics observed by the DE-2 satellite. *Journal of Geophysical Research*, 91, 1535.
- Fossat E., G. Grec, and M. Pomerantz. 1981. Solar pulsations observed from the geographic South Pole: initial results. *Solar Physics*, 74, 59-63.
- Foster, J.C. and T.J. Rosenberg. 1976. Electron precipitation and VLF emissions associated with cyclotron resonance interactions near the plasmopause. *Journal of Geophysical Research*, 81, 2183-2192.
- Grec, G., E. Fossat, and M. Pomerantz. 1980. Solar oscillations: full disk observations from the geographic South Pole. *Nature*, 288, 541-544.
- Helliwell, R.A., J.P. Katsufakis, and M.L. Trimpi. 1973. Whistler-induced amplitude perturbation in VLF propagation. *Journal of Geophysical Research*, 78, 2, 4679.
- Helliwell, R.A., and J.P. Katsufakis. 1978. Controlled wave-particle interaction experiments. In *Upper Atmosphere Research in Antarctica*, Antarctic Research Series, Volume 29, L.J. Lanzerotti and C.G. Parks (eds.), Washington, D.C.: American Geophysical Union.
- Helliwell, R.A., S.B. Mende, J.H. Doolittle, W.C. Armstrong, and D.L. Carpenter. 1980. Correlations between 4278 optical emissions and VLF wave events observed at L4 in the Antarctica. *Journal of Geophysical Research*, 85, 3376.
- Helliwell, R.A., D.L. Carpenter, and T.R. Miller. 1980. Power threshold for growth of coherent VLF signals in the magnetosphere. *Journal of Geophysical Research*, 85, 3360.
- Helliwell, R.A., U.S. Inan, J.P. Katsufakis, and D.L. Carpenter. 1986a. Beat excitation of whistler mode sidebands using the Siple VLF transmitter. *Journal of Geophysical Research*, 91, 143.
- Helliwell, R.A., D.L. Carpenter, U.S. Inan, and J.P. Katsufakis. 1986b. Generation of band-limited VLF noise using the Siple transmitter: a model for magnetospheric hiss. *Journal of Geophysical Research*, 91, 4381.
- Imhof, W.L., J.B. Reagan, H.D. Voss, E.E. Gaines, D.W. Datlowe, and J. Mobilia, R.A. Helliwell, U.S. Inan, and J. Katsufakis. 1983. The modulated precipitation of radiation belt electrons by controlled signals from VLF transmitters. *Geophysical Research Letters*, 10, 615.
- Kimura, I., H. Matsumoto, T. Mukai, K. Hashimoto, T.F. Bell, U.S. Inan, R.A. Helliwell, and J.P. Katsufakis. 1983. EXOS-B/Siple Station VLF wave-particle interaction experiments: 1. General description and wave-particle correlations. *Journal of Geophysical Research*, 88, 282.
- Inan, U.S., D.L. Carpenter, R.A. Helliwell, and J.P. Katsufakis. 1985. Subionospheric VLF/LF phase perturbations produced by lightning-whistler induced particle precipitation. *Journal of Geophysical Research*, 90, 7457.
- Kintner, P.M., R. Brittain, M.C. Kelly, D.L. Carpenter, and M.J. Rycroft. 1983. In situ measurements of transionospheric VLF wave injection. *Journal of Geophysical Research*, 88, 7065.

- Jacklyn, R.M., M.L. Duldig, and M.A. Pomerantz. 1984a. Cosmic ray intensity waves and the north-south anisotropy. *Proceedings of the Astronomical Society of Australia*, 5, 581.
- Lanzerotti, L.J., and C.G. Park, eds., 1978. *Upper Atmosphere Research in Antarctica*, Antarctic Research Series, Volume 29. Washington, D.C.: American Geophysical Union.
- Lanzerotti, L.J. 1978. Studies of geomagnetic pulsation. In *Upper Atmosphere Research in Antarctica*, Antarctic Research Series, Volume 29, L.J. Lanzerotti and C.G. Parks (eds.). Washington, D.C.: American Geophysical Union.
- Lanzerotti, L.J., and S.M. Krimigis. 1985. Comparative magnetospheres. *Physics Today*, 38 (11), 24.
- Nagata, T., and T. Hirasawa. 1982. IMS results in Antarctica. In *The IMS Source Book*, C.T. Russell and D.J. Southwood, (eds.). Washington, D.C.: American Geophysical Union.
- Pomerantz, M.A., and S.P. Duggal. 1972. North-south anisotropies in cosmic radiation. *Journal of Geophysical Research*, 77, 263-265.
- Pomerantz, M.A. 1978. Cosmic rays. In *Upper Atmosphere Research in Antarctica*, Antarctic Research Series, Volume 29, L.J. Lanzerotti and C.G. Park (eds.). Washington, D.C.: American Geophysical Union.
- Pomerantz, M.S., S.P. Duggal, A.J. Owens, M.F. Tolba, and C.H. Tsao. 1982. Cosmic ray north-south anisotropy: The role of the interplanetary magnetic field. *Journal of Geophysical Research*, 87, 10325-10330.
- Roederer, J.L., E.A. Bering, J.R. Benbrook, and W.R. Sheldon. 1985. X-ray microbursts and VLF chorus. *Journal of Geophysical Research*, 90, 10975.
- Rosenberg, T.J., R.A. Helliwell, and J.P. Katsufakis. 1971. Electron precipitation associated with very-low frequency emissions. *Journal of Geophysical Research*, 76, 8445-8451.
- Rosenberg, T.J., J.C. Siren, D.L. Matthews, K. Marthinsen, J.A. Holtet, A. Egeland, D.L. Carpenter, and R.A. Helliwell. 1981. Conjugacy of electron microbursts and VLF chorus. *Journal of Geophysical Research*, 86, 5819-5832.
- Rosenberg, T.J., P.B. Morris, and L.J. Lanzerotti. 1981. Excitation of magnetospheric hydromagnetic waves by solar-flare-induced change in ionospheric conductivity. *Physical Review Letters*, 47, 1343-1346.
- Rosenberg, T.J. 1982. Research at United States antarctic stations during the International Magnetosphere Study. In *The IMS Source Book*, C.T. Russell and D.J. Southwood (eds.). Washington, D.C.: American Geophysical Union.
- Rycroft, M.J. 1974. Antarctic observations available for IMS correlative analyses. In *The IMS Source Book*, C.T. Russell and D.J. Southwood (eds.), page 196, Washington, D.C.: American Geophysical Union.
- Sheldon, W.R., J.R. Benbrook, and C.G. Gelpi. 1985. Diurnal modulation of the quiet time penetrating electron flux. *Journal of Geophysical Research*, 90, 548.
- Southwood, D.J. 1974. Recent studies in micropulsation theory. *Space Science Review*, 16, 413.
- Smith, A.J., and D.L. Carpenter. 1982. Echoing mixed-path whistlers near the dawn plasmopause observed by direction-finding receivers at two antarctic stations. *Journal of Atmospheric and Terrestrial Physics*, 44, 973.
- Stansbery, E.G., and W.R. Sheldon. Longitudinal differences in electron precipitation near L=4. Submitted to *Journal of Geophysical Research*, 1985.
- Tolstoy, A., T.J. Rosenberg, and D.L. Carpenter. 1982. The influence of localized precipitation-induced D-region ionization enhancements on subionospheric VLF propagation. *Geophysical Research Letters*, 9, 563-566.
- Tolstoy, A., T.J. Rosenberg, U.S. Inan, and D.L. Carpenter. Model predictions of subionospheric VLF signal perturbations resulting from localized, electron precipitation-induced ionization enhancement regions. Submitted to *Journal of Geophysical Research*, 1986.
- Waynick, A.H., ed. 1985. *Geomagnetism and Aeronomy*. Washington, D.C.: American Geophysical Union.
- antarctic weather and climate from expeditions up to World War II. He lists about 100 antarctic meteorology books and papers, which were published between 1930-1950.
- Two major post-war expeditions before the International Geophysical Year (IGY) in 1957-1958 added substantially to the knowledge of antarctic weather and climate. One of these was the French expedition to Port Martin (66°49'S 141°24'E) from which Loewe (1956) provided the first detailed account on the energy, mass, and water budgets of the continent. The second was the Norwegian-Swedish-British expedition to Maudheim (71°3'S 10°56'W). Participants of this expedition obtained detailed climatic data for a climatically vulnerable ice shelf, along with a detailed analysis of polar boundary-layer processes by Liljequist (1957). The results of these expeditions contributed substantially to the pre-IGY knowledge of the antarctic climate.
- Convincing synoptic studies of weather and climate were not possible before the IGY, although the South African Weather Bureau attempted to produce hemispheric charts based in part on whaling ship reports. Conclusive analysis, however, could not be accomplished until the advent of manned stations, automatic weather stations, buoys, and satellites during and after the IGY. Our understanding of antarctic meteorology has advanced rapidly since then.

Antarctic observational systems

The long-term occupation of manned stations in Antarctica began during the IGY. In recent years, 25 meteorological stations have operated year-round in the 35 million square kilometers south of 60°S. This compares with 340 such stations in the United States, an area less than a third in size but with about 50 times more stations per unit area. Most of the stations ring the Antarctic; only two of them operate all year on the high interior antarctic plateau—the U.S. Amundsen-Scott South Pole Station at the geographic South Pole and the U.S.S.R. Vostok Station (78°28'S 106°48'E) which is also on the polar plateau.

Other observational systems are beginning to fill the gaps. Automatic weather stations with improved power supplies that include radioisotope generators, long-term storage batteries, and solar cells have become quite reliable. These are now used in the Ross Sea and on the Ross Ice Shelf, inland from the French station Dumont d'Urville (66°40'S 140°1'E) up to Dome C (74°50'S 120°E) to measure katabatic winds, inland from Casey Station (66°16'S 110°32'E), and on the Antarctic Peninsula. The southern oceans remain the most poorly observed region on Earth with

Meteorology

The weather and climate of Antarctica and how it influences the rest of the globe have fascinated explorers and scientists from the "Heroic period" of antarctic exploration that started with the first wintering on the *Belgica* in 1898-1899, through the "Mechanical expeditions" that began with Admiral Byrd's first expedition in 1928, and finally into the period of airplane-, satellite-, and computer-supported permanent scientific stations in the second half of the 20th century. In the *Compendium of Meteorology*, Court (1951) summarizes what had been learned about

only a few buoys periodically deployed in the open ocean and in the pack ice. However, satellites now provide much information about the southern oceans in such forms as cloud mosaics and passive microwave observations of sea ice (Zwally et al, 1983).

A number of special observation periods and facilities have supplemented the low-density observational systems in Antarctica. During the First GARP (Global Atmosphere Research Program) Global experiment (FGGE) in 1978-1979 several hundred ocean buoys were deployed. Also, constant-level balloons circled the southern oceans and crossed the continent. These provided atmospheric data and ice-sheet elevations. The U.S. station Plateau, built at an altitude of 3,600 meters, operated for 3 years and provided fascinating new insights into atmospheric boundary-layer structure and processes. Deep drilling and recovery of ice cores, which were done at Byrd Station (now Byrd Surface Camp) and are continuing at Vostok, are laying a basis for reconstructing Antarctica's climatic record. A clean-air facility at South Pole continues to provide data on snow and atmospheric chemistry.

New nations now are venturing into Antarctica. The stations built by these nations are not necessarily established in locations best suited for scientific purposes but are located where access is convenient. Improvements in the meteorological observational network therefore are most likely to come from improved technology and to a lesser extent from additional stations.

Large-scale circulation

Before the IGY relatively little was known about the large-scale circulation of the atmosphere of the southern hemisphere. Palmer (1945) described its observed broad features, but the precise position and movement of air masses and fronts were largely conjecture. Satellites have improved observation capabilities drastically (figure 1) and are now essential for weather prediction. Cloud-vortex observations and classification by Streten and Troup (1973) have made possible the first truly synoptic climatology for the southern oceans.

In a book published just before his death (Schwerdtfeger, 1984), Werner Schwerdtfeger summarized the present knowledge of the weather and climate of Antarctica. Meteorologists now recognize that the main features of antarctic circulation are a katabatic boundary-layer regime over the continent that is only weakly coupled to the air flow above it, and, in contrast, a strongly coupled and very energetic wind regime over the southern oceans in which winds and sea state surpass those of other oceans. This



Figure 1. NOAA-1 infrared photo mosaic of the Southern Hemisphere, June 18, 1971. Note that the continents are depicted lighter (colder) than the warmer ocean, and that the brightest (highest and coldest) clouds appear in the southern ocean depression vortices and the tropical systems over Indonesia. The gray scale shows approximate temperature values in °C.

latter feature was, of course, well known even 100 years ago to the crews of large sailing ships. The seasonal change in the circumpolar vortex up to the stratosphere and its cyclonic and anticyclonic systems are relatively well understood through the efforts of many, including Palmer, Schwerdtfeger, Streten, van Loon, and Taljaard.

The boundary-layer katabatic wind regime is a unique large-scale circulation feature on Earth. Radok (1973) has compared some aspects of this regime with the trade wind regime. Katabatic winds display an extraordinarily high degree of persistence and are a function of the surface-temperature inversion and terrain slope angle. In the initial models for these winds, the energetics invoked to cause air flow differed. Although these differences have not been resolved entirely, Parish and Bromwich (1986), using a model developed by Ball (1960), successfully reproduced the high spatial irregularity and strong topographic channeling of the flow that characterizes the observed wind regime (figure 2). An observation program, presently running in Adelie Land and using

automatic weather stations in a profile from the coast up to Dome C, should enhance understanding of the temporal change in the katabatic drainage.

Climate

Antarctica is the coldest and driest continent on Earth. Since the IGY, scientists have studied in detail the climate and its various geographic regimes. From the results of these investigations a fairly complete picture has emerged. The Soviet atlas of Antarctica (Bakaev, 1966), the American Geographical Society *Antarctic Map Folio Series* (Weyant, 1966, 1967), a contribution by Schwerdtfeger (1970) to the published *World Series of Climatology*, and several volumes in the American Geophysical Union *Antarctic Research Series* provide a comprehensive picture of the climate of Antarctica and its surrounding oceans.

The central antarctic plateau is a cold desert with annual mean temperatures between -50°C (South Pole) and -60°C (Plateau Station). The lowest temperature (-89.2°C) on Earth was recorded on the

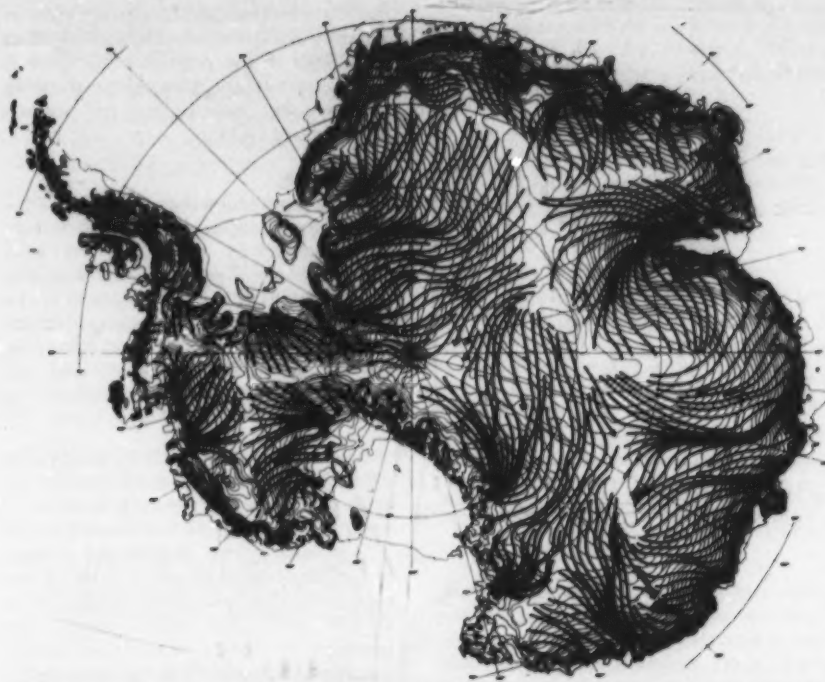


Figure 2. The surface wind field over the antarctic ice sheet. The heavy lines represent the streamlines of time-averaged surface air motion derived from solution of the Ball model over a square grid with 50 kilometers spacing (From Parish and Bromwich, 1986).

east antarctic plateau at Vostok Station in July 1983. Annual precipitation is about 7 centimeters water equivalent at geographic South Pole and 3 centimeters at Plateau Station. The coastal regions are much warmer (-10°C to -20°C), receive more precipitation, and have much stronger (katabatic) winds.

Few direct measurements are available from the extensive pack-ice zone that annually surrounds Antarctica, but clearly the ice modifies the antarctic climate considerably by reflecting solar radiation and by suppressing sensible and latent heat exchange between the ocean and the atmosphere (Fletcher, 1969). Satellite and buoy measurements are beginning to quantify this effect, which depends strongly on such ice characteristics as thickness and concentration. The sea ice distribution around Antarctica also affects cyclonic activity and vice versa—a greater ice extent in one sector or zone increases cyclogenesis there (e.g., Carleton, 1981).

Soon after the IGY, meteorologists recognized (Wexler, 1960) that the seasonal temperature variations in the stratosphere are much larger than those in the troposphere. Intense horizontal advection of maritime air frequently ventilates the interior of Antarctica and gives rise to the flat "coreless" winter temperatures* there instead of sharp winter minima. On the other hand, the antarctic stratosphere cools continuously until the sun returns and then

warms as much as 50°C in a month. Explosive stratospheric warmings often occur much earlier than the Sun's return. These are caused by subsidence associated with changes in the circulation patterns of the stratospheric circumpolar vortex.

Antarctica affects and is affected by global climate. Potential changes in the antarctic environment, induced by carbon dioxide, are beginning to be assessed (NAS, 1984). Stratigraphic, isotopic, particle, and entrapped gas (e.g., carbon dioxide) data derived from the deep ice cores taken at Byrd Station and Dome C and especially from the more than 2,000 meters of ice extracted so far at Vostok provide for the first time details of the most recent global glaciations that have been only outlined in ocean sediment cores.

Boundary-layer processes

Lettau (1971) has called the antarctic plateau a "test tube for meteorological theories" because its surface is flat and exceptionally uniform and because diurnal variations due to changes in solar elevation are small or absent. Numerous boundary-layer experiments conducted in Antarctica

*"Coreless" winters are winters in which the mean monthly temperatures during a number of months differ little from each other. This pattern is common in the Arctic as well as the Antarctic.

since the IGY have proved this to be true. Following the pre-IGY studies at Port Martin and Maudheim, Rusin (1961) produced the first major summary of the meteorological and radiational regime of Antarctica, based primarily on data from the Soviet stations established during the IGY.

Radiation is the most important component of the surface energy balance to strongly influence climate. Measurements at several plateau stations (cf. Weller, 1980) confirmed Rusin's largely negative radiation balances, but later comparison with coastal stations showed that the surface energy exchanges are more intense on the coast than over the interior of Antarctica. This runs counter to the popular view of the ice sheet as the main global heat sink, which in fact lies in the higher layers of the antarctic atmosphere (Radok, 1981). Carroll (1982) made the most recent energy balance measurements at South Pole Station with more modern equipment over 3 years. Even during the polar night, these measurements showed a high degree of short-term variability due to the frequent influx of maritime air.

The strong radiational cooling of the surface, on the other hand, produces the katabatic wind regime and associated extensive snow drifting, which was studied in detail by Budd et al (1966) at Byrd Station. Radiational cooling also produces extraordinarily stable stratifications, wind shears, and associated optical phenomena. The vertical profiles of temperature and wind through the inversion layer were described by Kuhn et al (1977). They are highly complex (figure 3), represent the most stable stratification found anywhere on Earth, and provide a major challenge to turbulence theory.

Atmospheric and snow chemistry

The concept that the polar regions are pollution-free areas was abandoned after long-term environmental monitoring stations were installed in both regions. While cleaner than the Arctic, the Antarctic nevertheless has anthropogenic substances present in its atmosphere, despite the long transport from industrial sources across the stormy southern oceans.

The GMCC (Global Monitoring for Climate Change) station at the geographic South Pole has contributed substantially to our knowledge of global atmospheric chemistry. The rising levels of carbon-dioxide, measured at South Pole since about 1958 by Keeling (1984), show the same global trends as at lower latitudes (figure 4). Halocarbons are present in the antarctic atmosphere (Robinson et al, 1983), but their increase appears to be slowing down. Also their concentration is lower than in the Arctic. Aerosols include sea salt (even

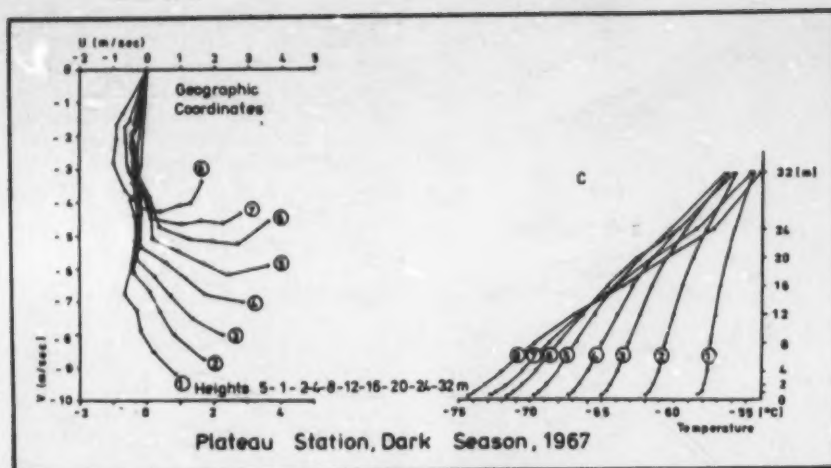


Figure 3. Features of the polar night boundary layer at Plateau Station, Antarctica. The vertical profiles of temperature and wind are shown for eight different sets of observations (From Kuhn et al. 1977).

at the South Pole), crustal material, and sulfur compounds. Some of the latter originate from the volcanoes of Antarctica, particularly Mt. Erebus on Ross Island.

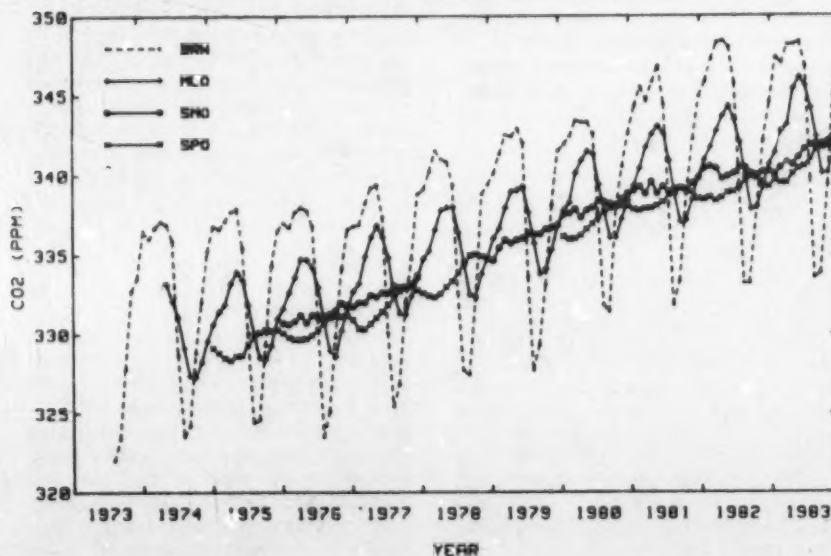
Both gases and aerosols have been used to examine the long-range transport and mixing of tropospheric and stratospheric air. Modern techniques employed include lidars, balloons that can ascend up to 30 kilometers to sample nitrous oxide and aerosols, and scanning photometers on satellites such as the Nimbus-7 sun photometer SAM II (Stratospheric Aerosol Measurement) to examine aerosol layers.

The snow surface is a convenient filter that collects and stores all the material that

falls onto it. Snow stratigraphy studies have, therefore, allowed a glimpse into the past: chemical conditions that existed over the ice sheet. Radionuclides show nuclear test horizons. Lead and other trace metals are present, although the concentrations indicate that Antarctica is still little affected by industrial lead pollution (Boutron and Patterson, 1983). The most spectacular results come from analyzing the oxygen isotopes of deep cores to reconstruct paleoclimates (Robin, 1983) and gas samples encapsulated in bubbles in the ice to show the low pre-industrial levels of carbon-dioxide (Neftel et al., 1982).

These results have shown that Antarctica is not isolated from the rest of the globe,

Figure 4. Monthly mean carbon-dioxide concentrations from continuous measurements at Barrow, Alaska (BRW), Mauna Loa, Hawaii (MLO), Samoa (SMO) and South Pole (SPO). Values are in parts per million with respect to dry air (From NOAA/GMCC-Boulder, Colorado).



but that processes and human activities as far away as the Northern Hemisphere affect conditions in the Antarctic. Nowhere is this more evident than in the startling discovery that antarctic snow and penguin eggs contain DDT.

Conclusion

Great progress has been made since the IGY in understanding antarctic meteorology and climatology. Basically, we now understand the major seasonal features of atmospheric circulation, the climate of the continent, the radiation and energy balance that affect climate and circulation (including the katabatic wind regime), and the transport of gases and aerosols to Antarctica.

Interest in antarctic meteorology and climatology has increased substantially, as exemplified by the growing number of scientific papers listed in the quadrennial U.S. national reports on polar meteorology to the International Union of Geodesy and Geophysics (Robinson, 1983; Radok, 1979; Weller, 1975 and earlier ones). The problems of climate research, as part of the World Climate Program, have put a new focus on the polar regions and have brought polar meteorologists and climatologists together with other atmospheric scientists, oceanographers, and glaciologists. Improvements in modern measuring techniques, which include satellites, buoys, radars, automatic weather stations, and other tools, will provide better coverage of the polar regions in the future.

Although we have a much better understanding now than before the IGY of the broad features and processes of the antarctic atmosphere, many questions remain. Some of the major problems that wait to be solved include the large-scale nature of the antarctic heat sink and its variations (i.e. the changes of the energy budget on synoptic time-space scales), coupled air-ice-sea interactions, antarctic teleconnections (i.e. how does Antarctica affect global processes?), and the response of Antarctica to climate change (e.g. carbon-dioxide warming). These are broad, interdisciplinary problems in the context of which antarctic meteorology will become part of a truly global research enterprise.

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References

- Bakaev, V.G. (ed.). 1966. *Atlas of Antarctica* (in Russian). Moscow, U.S.S.R.: USSR Academy of Sciences.
- Businger, J.A. (ed.). 1977. *Meteorological studies at Plateau Station, Antarctica*.

- Antarctic Research Series, Vol. 25. Washington, D.C.: American Geophysical Union.
- Court, A. 1951. Antarctic atmospheric circulation. In *Compendium of Meteorology*, T.F. Malone (ed.), American Meteorological Society.
- Director of Meteorology. 1960. *Antarctic meteorology*. Pergamon Press.
- Polar Research Board, National Academy of Sciences. 1984. *Environment of West Antarctica: Potential carbon dioxide-induced changes*. Washington, D.C.: National Academy of Sciences, National Academy of Sciences, National Academy Press. 236 pages.
- Radok, U. 1979. Polar meteorology and climatology, 1975-1978. *Reviews of Geophysics and Space Physics* 17, 1772-1781.
- Robin, de Q., G. (ed.). 1983. *The climatic record in polar ice sheets*. Cambridge, United Kingdom: Cambridge University Press.
- Robinson, E. 1985. Polar meteorology and climatology, 1979-1982. In *U.S. national report to International Union of Geodesy and Geophysics (1979-1982)*, 1048-1064. Washington, D.C.: American Geophysical Union.
- Rubin, M.J. (ed.). 1966. *Studies in Antarctic Meteorology*. Antarctic Research Series, Volume 9. Washington, D.C.: American Geophysical Union.
- Rusin, N.P. 1961. *Meteorological and Radiational Regime of Antarctica* (in Russian). Gidrometeorologicheskoe Izdel'stvo, Leningrad. Translated by Israel Scientific Translations, 1964.
- Schwerdtfeger, W. 1970. Climate of the Antarctic. In *Climates of the Polar Regions*, S. Orvig (ed.), World Survey of Climatology, 14. Amsterdam, the Netherlands: Elsevier.
- Schwerdtfeger, W. 1984. *Weather and Climate of the Antarctic*. Amsterdam, the Netherlands: Elsevier.
- Weller, G. 1975. Polar Meteorology. *Reviews of Geophysics and Space Physics*, 13, 710-716 and 808-811.
- Weyant, W.S. 1966. The antarctic atmosphere: climatology of the troposphere and lower stratosphere. *Antarctic Map Folio Series*, folio 4. New York, New York: American Geographical Society.
- Weyant, W.S. 1967. The antarctic atmosphere: climatology of the surface environment. *Antarctic Map Folio Series*, folio 8. New York, New York: American Geographical Society.
- Other selected references**
- In addition there are several planning documents by the National Research Council and others and conference proceedings.
- Ball, F.K. 1960. Winds on the ice slopes of Antarctica. In *Antarctic Meteorology*, Proceedings of the Symposium held at Melbourne, 1959. Oxford, United Kingdom: Pergamon Press.
- Boutron, C.F., and C.C. Patterson. 1983. The occurrence of lead in Antarctic recent snow, firm deposited over the last two centuries and prehistoric ice. *Geochimica et Cosmochimica Acta*, 47.
- Budd, W.F., W. Dingle, and U. Radok. 1966. The Byrd snowdrift project: outline and basic results. In *Studies in antarctic meteorology*, M. Rubin (ed.), Antarctic Research Series, Volume 9, 71-134. Washington, D.C.: American Geophysical Union.
- Carleton, A.M. 1981. Ice-ocean-atmosphere interactions at high southern latitudes in winter from satellite observations. *Australian Meteorological Magazine*, 29, 183-195.
- Carroll, J.J. 1982. Long-term means and short-time variability of the surface energy balance components at the South Pole. *Journal of Geophysical Research*, 87 (C6): 4277-4286.
- Fletcher, J.O., 1969. Ice Extent on the Southern Ocean and its Relation to World Climate. Memorandum RM-5793-NSF. California: The Rand Corporation, 108 p.
- Keeling, C.D. 1984. Atmospheric and oceanographic measurement needed for establishment of data base. In *The Potential Effects of Carbon Dioxide-Induced Climatic Changes in Alaska*, Miscellaneous Publications, 83-1. Fairbanks, Alaska: University of Alaska.
- Kuhn, M., H. Lettau, and A. Riordan. 1977. Stability-related wind spiraling in the lowest 32 meters. In *Meteorological Studies at Plateau Station*, A.J. Businger (ed.), Antarctic Research Series, Volume 25. Washington, D.C.: American Geophysical Union.
- Lettau, H.H. 1971. Antarctic atmosphere as a test tube for meteorological theories. In *Research in the Antarctic*, L.O. Quam (ed.), papers presented at the Dallas Meeting 1968 of the American Association for the Advancement of Science (AAAS). AAAS Publication, 93: 443-475.
- Liljequist, G.H. 1956 and 1957. Energy exchange of an antarctic snowfield. Norway-Britain-Sweden Antarctic Expedition 1949-1952, Scientific Results, Part 1, volume 2: 4 issues, 289 pp.
- Loewe, F. 1956. *Etudes de Glaciologie en Terre Adélie, 1951-1952. Expéditions Polaires Françaises*, Paris (B. Valtat, ed.), No. 1247-159 pp.
- Neftel, A., H. Oeschger, J. Schwander, B. Stauffer and R. Zumbener. 1972. New measurements of ice core samples to determine the carbon-dioxide content of the atmosphere during the last 40,000 years. *Nature*, 295, 220-223.
- Palmer, C.E. 1945. Southern hemisphere synoptic meteorology. In *Handbook of Meteorology*. Berry, Bollay, and Beers (eds.). New York, New York: McGraw-Hill Book Company Inc.
- Parish, T.R., and D.H. Bromwich. The surface wind field over the Antarctic ice sheet. In preparation.
- Radok, U., 1973. On the energies of the surface winds over the antarctic ice cap. In *Energy fluxes over polar surfaces*, WMO Technical Note 129. Geneva, Switzerland: World Meteorological Organization.
- Radok, U. 1981. The lower atmosphere of the polar regions. *Geologische Rundschau*, 70, 703-724.
- Robinson, E., W.L. Barnesberger, F.A. Menzia, A.S. Waylett, and S.F. Waylett, 1984. Atmospheric trace gas measurements at Palmer Station, Antarctica: 1982-1983. *Journal of Atmospheric Chemistry*, 2, 65-81.
- Streten, N.A., and A.J. Troup. 1973. A synoptic climatology of satellite observed cloud vortices over the Southern Hemisphere. *Quarterly Journal of the Royal Meteorological Society*, 99: 56-72.
- Taljaard, J.J., H. van Loon, H.L. Crutcher, and R.L. Jenne. 1969. Climate of the upper air, Part 1 - Southern Hemisphere, Volume 1, Temperature, dew points, and heights at selected pressure levels. NAVAIR 50-1C-55, Washington, D.C., 135 p.
- van Loon, H., J.J. Taljaard, R.L. Jenne, and H.L. Crutcher. 1971. Climate of the Upper Air: Southern Hemisphere, Volume II. NAVAIR 50-1C-56 and NCAR TN/STR-57, Boulder, Colorado: 39 pp.
- Weller, G. 1980. Spatial and temporal variations in the south polar surface energy balance. *Monthly Weather Review*, 108, 2006-2014.
- Wexler, H. 1959. Seasonal and other temperature changes in the antarctic atmosphere. *Quarterly Journal of the Royal Meteorological Society*, 85, 196-208.

Zwally, H.J., J.C. Comiso, C.L. Parkinson, W.J. Campbell, F.D. Carsey, and P. Gloersen. 1983. *Antarctic sea ice, 1973-1976: Satellite passive-microwave observations*. NASA Publications SP-459, 206 pp.

Physical oceanography

During the last 30 years, circumpolar and regional surveys have significantly advanced scientific understanding of the oceans surrounding Antarctica. More recently, research has focused on specific elements or processes within the southern oceans. During all phases of this research, international collaboration has been an important component, as has the application of state-of-the-art technology including moored and drifting instrumented arrays and sensors aboard satellites.

International Geophysical Year programs

The antarctic programs for the 1957-1958 International Geophysical Year (IGY) included an extensive southern oceans component (Gordon and Baker, 1969). Taken over 3 consecutive austral summers, the IGY data set, which marked renewed interest in the region, is a comprehensive, nearly synoptic representation of the southern oceans. Because most data were taken along supply routes to antarctic stations, the data set is not uniformly distributed, but it does permit time variability studies during the 3 year and studies over decades by comparison with the 1930's data collected by the British *Discovery* expeditions.

Use of the mechanical bathythermograph, which was newly available to scientists during the IGY, was a key factor in the scientific success of the IGY oceanography effort. The mechanical bathythermograph, which gives a continuous record of water temperature and depth as the instrument is lowered and raised, provided a high spatial resolution picture of the thermal structure of frontal zones and indicated where eddies exist within the polar front zone (Wexler, 1959).

Oceanography during the 1960's and 1970's

Since the IGY, antarctic supply ships have continued to obtain bathythermograph data and have extended this valuable, although spatially and temporally incomplete, time series. More recently, oceanographers, working from research ships and some supply ships, have used expendable bathythermograph (XBT) probes to measure temperature more precisely to deeper levels. For example, XBT probes were an important part of the late 1970's International Southern Oceans Studies (ISOS). During ISOS oceanographers

used the observation capabilities of the supply ship to obtain a set of repeated XBT lines along various routes. Such measurements have been fundamental to the study of the southern oceans frontal zonation structure and heat storage.

Between 1961 and 1979, most of the circumpolar belt was surveyed. From 1962 to 1972 during 55 cruises, the ice-strengthened U.S. research ship *Eltanin* covered 410,000 miles and obtained a comprehensive multi-disciplinary data set within some 80 percent of the southern oceans. Renamed the *Islas Orcadas* and operated jointly with Argentina, the *Eltanin* continued the circumpolar survey from 1974 to 1979 and carried the survey into the South Atlantic. Part of the southwest Indian Ocean sector was surveyed in 1974 by the research ship *Conrad*, which is part of the University-National Oceanographic Laboratory System supported by the National Science Foundation.

The *Eltanin/Islas Orcadas* hydrographic data greatly enhanced our picture of the thermohaline stratification, water masses, fronts, and currents within the circumpolar belt and continental margins of Antarctica. *Eltanin* data allowed more accurate mapping and volumetric determination of temperature-salinity modes of water masses. This has generated a number of new concepts about water mass formation processes and rates. New sites where bottom water is formed were located, as well as evidence for deep convection of the Weddell Gyre. The *Eltanin/Islas Orcadas* hydrographic data are a primary component of the *Southern Ocean Atlas* (Gordon and Molinelli 1982; Gordon and Baker 1982).

During the period of the *Eltanin* observations, technology continued to evolve. Serial hydrographic stations were replaced with continuous *in situ* measurements of the thermohaline stratification. These systems (STD and then the CTD) produced far better resolution of the vertical stratification and enabled oceanographers to detect relatively intense fine structure in the frontal zone and continental margin stratification.

While hydrographic technology advanced, the use of tracer geochemistry also evolved. Tracer distributions (such as stable isotopes of oxygen, tritium, carbon-14, and freon) provide a view of the integrated effects of ocean, ocean-glacial ice, and ocean-atmosphere exchange processes at various scales. With these data oceanographers are able to estimate the time scale of phenomena as well as give more "control" of the water types forming specific water masses.

In the austral summers of the late 1960's and 1970's, the western segment of the

Weddell Gyre was surveyed as part of the International Weddell Sea Oceanographic Expedition (IWSOE). During this work, which was staged from icebreakers and included scientists from the United States and Norway, oceanographers collected data within the fringes of the summer and multi-year sea-ice fields. Similar studies were conducted in the Ross Sea from U.S. icebreakers and lead to much improved resolution of the characteristics of the oceanic regime along continental margin south of the New Zealand/Australian sector. These studies improved our concepts of formation and production rates of Antarctic Bottom Water, intensity and structure of the shelf-slope front, continental shelf oceanography, and the role of the ocean in the glacial ice balance.

During the 1970's the International Southern Ocean Studies (ISOS) program focused on the Antarctic Circumpolar Current (ACC). This program concentrated on the Drake Passage but included some observations southeast of New Zealand.

With data from the ISOS program, oceanographers established a reliable value for the total baroclinic and barotropic transport of the ACC (125,000,000 cubic meters per second with about 70 percent of the net in the baroclinic mode) and for its variability (roughly 20 percent). This variability seems closely related to the zonally average wind stress acting on the circumpolar belt with a lag-time of about 1 week. The hydrographic data reveal a multi-filament structure for the ACC as it passes through the Drake Passage. These alternating jets of eastward flow with zones of weak flow or counterflow are associated with thermohaline frontal zones. The fronts display meanders or wave-like structures and generate eddies and rings. If the Drake Passage results are indeed typical of the circumpolar belt, these time varying features, which accomplish significant meridional heat flux, may be the primary mechanism to balance the oceanic heat loss south of the ACC.

During the 1978-1979 First GARP Global Experiment (FGGE), oceanographers used the experiment's extensive drifter array that was tracked by satellites to conduct a circumpolar study of southern oceans circulation. The FGGE drifters provided air pressure data, which enabled scientists to calculate better the geostrophic wind over the ocean. The trajectories of the FGGE drifters addressed the distribution of the circulation variability at various spatial scales including that of the mesoscale eddy field within the ACC. These factors also were detected from space in 1978 from the altimeter aboard the satellite SEASAT. SEASAT allowed synoptic determination of the wind stress on the ocean surface and of the wave field.

Weddell Sea study, 1981-1982

The *Discovery*, *Eltanin*/Islands *Orcadas* and *IWSOE* data sets included only the ice-free areas or, at best, the edges of the summer sea-ice fields. Until the 1981-1982 austral summer, these areas of the southern oceans were the only areas that had been studied extensively. In October and November 1981, the 137-meter Soviet icebreaker *Mikhail Somov* supported a joint U.S.-U.S.S.R. program in the Weddell Sea. During this cruise along the Greenwich meridian, U.S. and Soviet scientists obtained oceanographic data from well within the sea-ice cover, close to the time of its maximum extent. The *Somov* data set revealed for the first time the condition of the ice-covered ocean after the cumulative effects of winter.

These data have improved estimates of deep- to surface-water heat flux and have enabled oceanographers to describe some of the basic properties that are responsible for generating polynyas. However, the oceanic conditions under the extensive seasonal sea-ice cover around Antarctica remain the biggest "blind spot" in our view of the southern oceans structure. Observation within the sea-ice cover, particularly during the winter, represents an aspect of southern oceans research for which we are still essentially in a survey phase.

Satellites and oceanography

During the past decade, satellites have contributed greatly to our knowledge and understanding of the southern oceans and promise to be a major factor in future advances. Passive microwave data allow us to map sea-ice characteristics and the advance and retreat of sea ice without cloud interference. Visible and infrared radiation sensors have been developed to define the locations and variability associated with the frontal zones under cloud-free conditions.

The brief SEASAT mission of 1978 demonstrated the potential application of the scatterometer (for sea-level winds) and the altimeter (for sea-surface elevation). With only 3 months of data, circumpolar mapping of surface temporal variability of the Antarctic Circumpolar Current revealed coherent features over large scales, specifically ocean basins.

Conclusion

Progress has been impressive since the IGY. This paper cannot possibly provide a complete literature review, but some key papers, which review various segments of the field, are listed below. For review of general oceanography and water mass formation: Warren, 1981; Gordon, 1983; Killworth, 1983; and Carmack, 1984; Jacobs, Fairbanks, and Horibe, 1985; and the SCOR Working Group 74 Report, in

press. For review of the Antarctic Circumpolar Current and fronts: Bryden, 1983; Gordon, 1983; Hofmann, 1985; Whitworth, 1985; Nowlin and Klinck, (submitted to *Reviews in Geophysics and Space Science*). For recent application of satellite technology: Zwally et al, 1983; Fu and Chelton, 1984; Garrett, 1961; and Cheney, Marsh, and Beckley, 1983.

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References

- Bryden, H.L. 1983. The Southern Ocean. In *Eddies in Marine Science*, ed. A.R. Robinson. Berlin, Federal Republic of Germany: Springer-Verlag.
- Carmack, E.C. In press. Circulation and mixing in ice-covered waters. In *Air-Sea Interaction*, Proceedings of NATO Advanced Study Institute, Maratea, Italy 1981. Brussels, Belgium: North Atlantic Treaty Organization.
- Cheney, R.E., J.G. Marsh, and B.D. Beckley. 1983. Global mesoscale variability from collinear tracks of SEASAT altimetry data. *Journal of Geophysical Research*, 88(67): 4343-4354.
- Fu, L. and D.C. Chelton. 1984. Temporal variability of the Antarctic Circumpolar Current observed from satellite altimetry. *Science*, 226: 343-346.
- Garrett, J.F. 1981. Oceanographic features revealed by the FGGE drifting buoy array. In *Oceanography from Space*, J.F.R. Gower, ed. New York, New York: Plenum Press, pp 61-69.
- Gordon, A.L. 1983. Polar Oceanography. *Reviews of Geophysics and Space Science*, 21(5): 1124-1131.
- Gordon, A.L. and E.J. Molinelli. 1982. *Southern Ocean Atlas*, Thermohaline and Chemical Distributions, pages 3-11 and 233 Plates. New York, New York: Columbia University Press.
- Gordon, A.L. and F.W.G. Baker. 1968. *Oceanography*. Annals of the IGY, Volume XLVI. Oxford, United Kingdom: Pergamon Press.
- Gordon, A.L. and T.N. Baker. 1982. *Southern Ocean Atlas*, Objective Contouring, pages 15-31 and 15 Plates. New York, New York: Columbia University.
- Hofmann, E.E. 1985. The large scale horizontal structure of the Antarctic Circumpolar Current from the FGGE drifters. *Journal of Geophysical Research* 90: 7087-7097.
- Jacobs, S.S., R.G. Fairbanks and Y. Horibe. 1985. Origin and evolution of water masses near the Antarctic Continental Margins. In *Antarctic Research Series*, vol. 43, S.S. Jacobs (ed.). Washington, D.C.: American Geophysical Union.
- Killworth, P.D. Deep Convection in the World Ocean. 1983. *Reviews of Geophysical and Space Science*, 21: 1-26.
- Nowlin, W.D. and J. Klinck. The Antarctic Circumpolar Current. Submitted to *Reviews in Geophysics and Space Science*.
- Warren, B.A. 1981. Deep Circulation of the World Ocean. In *Evolution of the Physical Oceanography*, B. A. Warren and C. Wunsch, (eds.). Cambridge, Massachusetts: MIT Press.
- Wexler, H. 1959. The Antarctic Convergence or Divergence. In *The Atmosphere and the Sea in Motion*, B. Bolin, (ed.). New York, New York: Rockefeller Institute Press.
- Whitworth, T. 1985. Monitoring the Transport of the Antarctic Circumpolar Current at Drake Passage. *Journal of Physical Oceanography*, 13: 2045-2057.
- Zwally, J.J. Cosmisio, C. Parkinson, W. Campbell, F. Carsey, P. Gloersen. 1983. *Antarctic Sea Ice, 1973-1976*. NASA Science and Technology Information Branch, Washington, D.C.

Earth science

Although only continental geophysics was included as an official part of the International Geophysical Year (IGY), geological observations were made by scientists participating in the oversnow traverses. Soon after the IGY, geology, as well as marine geology and geophysics, became an integral part of the U.S. research program. The accomplishments of the IGY have been followed by many others in the earth sciences; some of the major accomplishments are presented here.

Marine geology and geophysics

The marine program was conducted primarily from the ice-strengthened research ship *Eltanin*, which during its 10 years of continuous service crisscrossed more than two-thirds of the southern oceans (figure 1). Thirty-three of the 55 cruises included marine geology and geophysics. The results (*Antarctic Journal of the U.S.*, 1973; Hayes, 1972; Heirtzler, 1971; Heezen et al, 1972; Goodell et al, 1973), together with a number of cruises

on the *Islas Orcadas* (formerly the *Eltanin*) and other ships, have contributed fundamental information on bathymetry, sediment distribution and type, Neogene biostratigraphy and paleontology, and patterns of sea-floor magnetic anomalies. The Deep Sea Drilling Project Antarctic Legs (28 and 35) and Sub-Antarctic Legs (29, 35, 71, 90) have provided the data base for the record older than that attainable with piston cores.

Eltanin cores provided material for an important early contribution on the correlation of microfossil assemblages and the paleomagnetic record in deep-sea cores (Hayes and Opdyke, 1967). From studies of deep-sea cores, proceeding from piston cores to the Deep Sea Drilling Project cores, scientists have developed a high-latitude biostratigraphy. This biostratigraphy has helped to establish important reference sections for much of the late Mesozoic and Cenozoic in the Sub-Antarctic (Legs 29, 36, 71, and 90) but only for parts of the latest Paleogene and Neogene for the Antarctic (Legs 28 and 35). From micro-paleontologic studies of floras and faunas of these sections, earth scientists have been able to recognize biogeographic patterns for the Cenozoic (Kennett, 1978a). The pattern shows marked changes at the Eocene-Oligocene boundary and at the transition from the Oligocene to the Miocene. The former records the establishment of assemblages with distinct polar characteristics; the latter shows a transition to the present-day pattern of steep gradients of faunal and floral diversity. The transitions are interpreted in terms of ice formation around or on the antarctic continent.

Paleoenvironmental studies also have used the record of ice-rafted debris (IRD) and disconformities. Watkins et al (1974) presented a model of preferential IRD deposition in high latitudes during interglacials and in lower latitudes during glacial maxima. Subsequently, Keany et al (1976) took into account the common occurrence of manganese nodules with IRD maxima. Another model proposed by Watkins et al. (1982) uses the rates of accumulation of manganese microneodules to

- remove the effects of bottom-current winnowing
- establish the true IRD accumulation rate
- estimate the relative changes in iceberg transport of debris.

Marine geologists also have shown that IRD can be correlated with the position of the Polar Front and that the first major northward migration of the IRD maximum occurred in late Miocene time (Ciesielski et al, 1982). Widespread disconformities in the cores are thought to reflect varia-

tions in the intensity of bottom water circulation and may be associated with manganese-nodule pavements (Kennett and Watkins, 1976). From detailed investigation of disconformities, scientists have been able to interpret these features in such terms as the influence of the Antarctic Circumpolar Current on sedimentation on the Falkland Plateau (Ciesielski et al, 1982; Ciesielski and Weaver, 1983) and the effects of Circumpolar Deep Water and Antarctic Bottom Water on the Pliocene through Holocene record of the deep oceans (Osborn et al, 1983; Ledbetter and Ciesielski, 1986). The record demonstrates significant temporal variations in water mass activity through time.

Biometric analysis (e.g., Malmgren and Kennett, 1972) has proved useful in deriving paleoenvironmental information. In these studies, analysis of foraminifera from surface sediment established frequency and coiling characteristics that relate to latitude (water temperature). Such data can be used for down core interpretation of paleoenvironments.

Quaternary paleoenvironments have been the object of much investigation under the stimulus of the CLIMAP project. Cores from the Sub-Antarctic in the Indian Ocean were used by Hays et al (1976a) to demonstrate a relationship between the Earth's orbital parameters and glacial maxima, thus providing the geological support for the Milankovitch theory of ice ages. Further, Hays et al (1976b), using cores from the Atlantic and southwest Indian Oceans, developed a radiolarian-based, high-resolution biostratigraphy linked to changes in isotopic oxygen-18 values for the last 150,000 years. They established that at the last glacial maximum (18,000 years ago) the Polar Front was displaced northwards as much as 7° latitude from its present position, but the apparent lack of change in the position of the Subtropical Convergence led them to infer a contraction in the width of the Sub-Antarctic waters and an increase in the thermal gradient in those latitudes. In subsequent work based on diatom assemblages and preservation, Burckle (1984) has shown that 18,000 years ago

- a northward shift in the late-spring to early-summer annual maximum extent of the sea ice occurred, but full summer conditions were probably similar to those prevailing today
- the Weddell gyre intensified
- the Weddell polynya was displaced northward a few degrees.

In another study, Dow (1978) inferred that 18,000 years ago temperatures were 2.2°C colder than today and that the Antarctic Convergence advanced to lower

latitudes six times in the last 600,000 years. *Eltanin* cores continue to yield new results, such as detailed dissolution and water-mass patterns in the southeast Indian Ocean for the Pleistocene to Recent (Williams et al, 1985a; 1985b).

Oxygen-isotope analysis of forams have established a trend of steadily declining isotopic oxygen-18 values with superimposed sharp steps and fluctuations through the Cenozoic (Shackleton and Kennett, 1975). The isotopic oxygen-18 values, which reflect both water temperature and ice volume changes, have been interpreted with respect to the glacial history of Antarctica and paleoclimate (Kennett, 1978b). The oxygen-isotope signals, the history of IRD, the record of disconformities, the northward migrations of the biosiliceous province, and the faunal and floral characteristics combine to suggest that, following an early cooling at the Eocene-Oligocene boundary, a major cooling occurred in the late Miocene, a warm period in the early Pliocene, a deterioration in the climate in the middle to late Pliocene, which was particularly marked at about 2.5 million years ago, and repeated fluctuations during the last 2 million years. The latter fluctuations seem to be directly related to northern hemisphere ice volume variations (Corliss, 1982).

Piston cores, taken largely from icebreakers and the *Eltanin*, together with other core material, have yielded much data on modern sediment dynamics within the continental shelf region and on the processes of glacial marine sedimentation. Using this data base, Anderson et al (1983) have proposed a model for polar glacial-marine sedimentation in which differences between the marine ice sheet environment and other types of antarctic coastline are brought out. The model emphasizes the influence of the great depth of the shelf on sedimentation processes and contrasts this with other modern glacially-dominated marine environments. The major role of resedimentation in sediment facies distributions on the shelf and abyssal plains, via submarine canyons, also is evident (Wright et al., 1983).

Marine geophysical surveys of the Ross Sea region established the unusual depth, about 500 meters, of the shelf and the presence of two major sedimentary basins separated by a major gravity high along the 180° meridian (Houtz and Davey, 1973; Hayes and Davey, 1975). These basins were subsequently drilled on Leg 28 of the Deep Sea Drilling Project (Hayes, Frakes, et al., 1975) and yielded important information on the inception of glaciation (see glacial geology section). The westernmost Ross Sea was not surveyed by those *Eltanin* cruises but was the focus of a recent multichannel seismic survey, which defined

a major rift basin with as much as 14 kilometers of sedimentary section, possibly Cretaceous or older at the base (Cooper and Davey, 1985). A similar survey off Wilkes Land (Eitrem et al, in press) has shown that margin to be a classic passive margin with well-defined seismic unconformities interpreted in terms of rift-onset, break-up and tectonic subsidence.

The marine geophysical data sets from the deep oceans have established the timing and kinematics of continental separation. Antarctica and Australia rifted apart in the Late Cretaceous but with very slow spreading until the Late Eocene (Cande and Mutter, 1982). The pattern of anomalies associated with the East Pacific Rise show separation of the Campbell Plateau from West Antarctica at about 80 million years and a relatively straight forward spreading history as far east as the continental intersection of the Eltanin Fracture Zone (Weissel et al, 1977). In the southeastern Pacific history is complicated by the presence of migrating triple junctions associated with Cenozoic reorganization of boundaries between the Pacific, Aluk, Antarctic and Farallon Plates (Cande et al, 1982) and ridge crest-trench collision along the Antarctic Peninsula (Weissel et al, 1977). The southernmost South Atlantic is also a complicated region and the Weddell Sea, in which anomalies possibly as old as M29 (more than 65 million years ago) have been identified (LaBrecque and Barker, 1981), is particularly important for understanding the early stages of evolution of Gondwana break-up. Lawver et al, (1985) have recently proposed a model for the evolution of the southernmost Atlantic. This model shows the major role that plate motions and evolving bathymetry have in controlling paleocirculation. Similar controls are evident for the gateway between Antarctica and Australia (Weissel and Hayes, 1972). The history of paleocirculation undoubtedly bears on the history of climate change (Kennett, 1978b).

Terrestrial geophysics

Continental geophysics has been largely confined to West Antarctica and the Transantarctic Mountains. The early oversnow traverses included seismic and gravity surveys. The results from these investigations, together with regional airborne magnetic surveys and subsequent detailed studies, established the basic framework of a 40-kilometer-thick crust under East Antarctica, the abrupt change in crustal thickness along the Transantarctic Mountains front, the thin (25 to 30 kilometer) crust of West Antarctica, the regional magnetic pattern, and the state of isostatic balance (Bentley, 1983; Behrendt et al, 1980).

The radio-echo sounding program, conducted in cooperation with the Scott

Polar Research Institute (Cambridge, England) and the Technical University of Denmark, collected ice thickness data and, during two years, magnetic data that have proved to be invaluable in understanding West Antarctica, the Pensacola Mountains region, a wide swath of the continent on the polar plateau side of the Transantarctic Mountains, and Wilkes Land (figure 2). (See Cameron and Bentley, this issue). The establishment of the sub-ice topography has been an important part of the development of ideas about geologic evolution (Dalziel and Elliot, 1982). More recent seismic work has confirmed the shallow depth to the Moho (Rooney et al, in press; Kim et al, 1986) and the rifted nature of the Ross Sea region (Cooper and Davey, 1985).

Terrestrial geology

Geological investigations have been conducted not only over much of the Transantarctic Mountains and West Antarctica but also in the Scotia Arc region. The Scotia Arc has long been of interest because it seems to form part of a link between South America and the geologically similar Antarctic Peninsula. Investigations in this region, that encompasses the northern Antarctic Peninsula and the Andes as far north as 50°S, have contributed not only to understanding the regional geology but also to more fundamental problems of orogenesis (mountain-formation processes) and marginal basin evolution. Studies of the structurally deformed metamorphic basement in the South Shetland Islands and South Orkney Islands (Dalziel, 1984), along with investigations in South Georgia and the Andes, have demonstrated the presence of a late Paleozoic-early Mesozoic active plate margin, which forms part of the Gondwana plate margin. Superimposed on that margin in the southern Andes and South Georgia is a younger plate margin that involved the creation of a marginal basin followed by its destruction with accompanying intense local deformation, including basement reactivation, and uplift. The history of this marginal basin and subsequent orogenesis has contributed to the broader understanding of Andean-type plate boundaries (Dalziel, 1981; 1985).

West Antarctica has been the focus of much research since it was realized that the Phanerozoic fold belts are associated with a relatively thin crust (20 to 30 kilometers thick) as compared with the 40-kilometer-thick crust of the east antarctic craton. The scattered outcrops of the rather inaccessible coastal regions of West Antarctica have been mapped (Sporli and Craddock, 1981) and the geologic history established.

Ellsworth Land and the southernmost Antarctic Peninsula also have been mapped

and studied in detail. Geologists have shown that these regions are part of the Mesozoic volcanic arc and back arc terranes that can be identified throughout much of the Antarctic Peninsula (Rowley et al, 1983). The most intriguing areas—the Ellsworth Mountains, the isolated nunataks that are scattered to the south and southwest, and the Thurston Island region—have yielded information critical for understanding the evolution of West Antarctica. The upper part of the Ellsworth Mountains sequence shows clear affinities with the Beacon rocks of the Transantarctic Mountains, including glacial beds and *Glossopteris*-bearing sandstones and shales (Craddock et al, 1965). The geology of the pre-glacial beds in the Ellsworth Mountains shows similarities with sequences in the Pensacola Mountains. However, the most striking aspects of the Ellsworth Mountains are the great thickness of the Paleozoic strata, their deformation in what seems to be a single episode in the Early Mesozoic, and the orientation of the structures NNW to SSE (nearly at right angles to the structural trends in the Pensacola Mountains and the projected trends on the Pacific margin of the continent).

Starting with Schopf (1969), geologists have proposed models that suggest that West Antarctica is made up of a number of discrete crustal blocks, some of which may be allochthonous (rock transported by tectonic processes over great distances from its original site of deposition). Preliminary paleomagnetic data on the Cambrian rocks showed that the Ellsworth Mountains may have rotated 90° counterclockwise (Watts and Bramall, 1981), but recent geological and geophysical work, conducted in cooperation with the British Antarctic Survey, is providing much new data. The Ellsworth Mountains and most of the nunataks in the Ellsworth-Thiel Ridge now are regarded as part of a single structural domain, the southern limit of which runs adjacent to the Transantarctic Mountains (Storey and Dalziel, in press). The Ellsworth crustal block is now better defined, but new paleomagnetic data suggest a 20° to 30° clockwise rotation with respect to East Antarctica (Grunow et al, in press) and raises about the previously inferred original position between the Cape Fold Belt and East Antarctica. These results (Dalziel et al, in press), plus those coming from Thurston Island, will help constrain models of the tectonic evolution of West Antarctica. These models, which can be tested in the coming decade, will bear on the reconstruction of the Pacific margin of Gondwana, the fragmentation and dispersal of that plate margin, and the paleobiogeographic and paleo-oceanographic development around Antarctica.

Investigations in the Transantarctic Mountains have established that the Beacon sequence is fundamentally similar to the other Gondwana sequences but particularly to that of South Africa. The Victoria Group of the Beacon Supergroup includes glacial deposits, a black shale unit, *Glossopteris*-bearing coal, Triassic vertebrate-bearing beds that pass upward into *Dicroidium* and coal-bearing strata, and a capping sequence of Jurassic basalts and comagmatic diabase sills intrusive into the Beacon rocks. With continuing study, geologists have been able to develop models for the evolution of the Beacon depositional basins and the relations to the sequences on adjacent Gondwana landmasses (Elliot, 1975; Collinson et al., in press).

Paleontology

Beacon rocks have yielded some highly significant paleontologic finds. Reptile, mammal-like reptile, and amphibian fossils recovered from the Lower Triassic Fremouw Formation were crucial in the paleontologic demonstration of the reality of continental drift and sea-floor spreading (Barrett et al., 1968; Elliot et al., 1970; Kitching et al., 1972). The composition and diversity of the early Triassic faunas not only demonstrate close taxonomic parallels with the *Lystrosaurus* zone of South Africa but now make paleoecological studies worthwhile (Hammer and Cosgriff, 1981).

Paleobotanical discoveries have been equally impressive. Initial recovery of abundant leaf impressions of the *Glossopteris* and *Dicroidium* floras have been followed by the discovery of silicified peat deposits associated with both floras. The Permian (*Glossopteris*) locality is one of only two known for that time period. The other locality, which is in Australia, lacks the exquisite preservation, diversity of components, and abundances of material that are present in Antarctica at Skaar Ridge, Mt. Augusta, near the head of the Beardmore Glacier (Schopf, 1982).

The deposit of Triassic age (*Dicroidium*) is unique because no other similar deposit exists anywhere in the world. These silicified peats are comparable to the Carboniferous coal balls of northern Europe and the Mid-West. Like them, the deposits permit such studies as the anatomy of plants, their histology, the occurrence of fungal attack, and the associated fruiting bodies (Stubblefield and Taylor, in press). These peat deposits are yielding data of fundamental importance in paleobotany.

Besides contributions to the study of the Gondwana flora and fauna, significant paleontological work has been done in other areas of the continent. Of the studies on the Cambrian faunas, the most interesting is probably the current work on the faunas from the Heritage Group in the Ellsworth Mountains. This fauna may be the most

diverse fauna of that age anywhere; furthermore, preservation is very good with many fossils preserved as shells rather than casts or molds. The fauna includes the only conodonts from the antarctic continent proper and has the youngest known *Archeocyathids*. A wide variety of trilobites are present and some primitive echinoderms, but most important are the 20 species of molluscs that include monoplacophorans, rostroconchs, cephalopod-like fossils and gastropods. The fauna is unique for the variety of primitive molluscs (Webers, 1972; Webers et al., in press). Collections from the Devonian strata in the Ohio Range and the Ellsworth Mountains have extended the Malvinokaffric faunal province into West Antarctica.

The investigation of the geology and paleontology of Seymour Island off the northern Antarctic Peninsula also has provided significant data. Seymour Island has possibly the best upper most Cretaceous-Lower Tertiary marine sequence in the Southern Hemisphere. The late Cretaceous molluscan fauna, particularly the ammonites, has considerable biogeographic importance as well as significance for Cretaceous-Tertiary boundary problems (Macellari, 1986). The Cretaceous-Tertiary boundary now is being located through paleontological studies of the associated faunas.

The late Eocene-early Oligocene invertebrate faunas are exceptionally well preserved, diverse, and abundant. A distinctive austral faunal province referred to as the Weddellian Province (Zinsmeister, 1979; 1982) has been observed, and these fossils also have yielded data bearing on heterochrony (Zinsmeister and Feldmann, 1984). A small number of marsupial fossil remains, the only terrestrial fossil mammals known from Antarctica, have been found in the Upper Eocene beds (Woodburne and Zinsmeister, 1982, 1984). These fossils are significant in the paleobiogeography of marsupials. They demonstrate that a land connection existed between the southern tip of South America and the Antarctic Peninsula during the latest Cretaceous and earliest Tertiary periods and that Antarctica acted as a dispersal corridor for marsupials between South America and Australia before Gondwana broke up (Zinsmeister, 1984).

On the other side of the continent, micropaleontologic work on core material from the ice-free valleys of southern Victoria Land and from McMurdo Sound (core samples in the latter case were provided by the New Zealand Antarctic Research Program) has yielded data on the timing of glacial events.

Mapping

From these geological and paleontological studies, as well as many others not men-

tioned in this paper, geological maps of the continent have been compiled. The 1:1,000,000 sheets of the principal outcrop areas produced by the American Geographical Society (AGS) (Bushnell and Craddock, 1969) with support from the National Science Foundation (NSF) and the AGS 1:5,000,000 map of the whole continent (Craddock, 1972) include data collected not only by the U.S. program but also by programs of other nations. More recently, NSF has funded the U.S. Geological Survey to publish quadrangle maps of parts of the Transantarctic Mountains and West Antarctica. Mapping by Dalziel and co-workers has been incorporated in a tectonic map of the Scotia Sea region (Anon, 1985). The antarctic sheets being compiled under the Circum Pacific Map (Craddock, in press) also include much data gathered by U.S. scientists.

Glacial geology

Since the IGY, earth scientists have made major advances in understanding the glacial history of Antarctica and, consequently, in understanding the history of climatic change in the Cenozoic. The data comes primarily from five sources—the study of piston cores from the deep ocean (obtained largely during cruises of *Eltanin*), more recent continental drilling in the ice-free valleys of southern Victoria Land, marine cores drilled from McMurdo Sound, the Deep Sea Drilling Project Legs 28 and 35, and studies of the terrestrial record of glaciation.

The deep-ocean cores have provided much data from ice-rafted debris, disconformities, sediment type, and the contained fossils on the changes in the behavior of water masses and the position of the Polar Front. These changes most likely are related to variations in the volume of the ice sheets on Antarctica. The deep-sea record has yielded data primarily on the changes during Pliocene to Recent time; however, much important information on pre-Pliocene events has been obtained from the Maurice Ewing Bank (51°S 43°W) (Ciesielski et al., 1982).

Investigations in southern Victoria Land and the McMurdo Sound region have included both the Dry Valley Drilling Project coring and the geologic mapping of glacial deposits and features (Stuiver et al., 1981; Denton et al., 1984). The results of these studies clearly show that the ice-free valleys of southern Victoria Land have been largely deglaciated for more than 4 million years, are uplifted fjords, and contain a record of glacial events going back to the Late Miocene. It is also evident that there have been glacial advances from the Ross Sea side as well as from the polar plateau. Detailed mapping has built a chronology of glacial fluctuations and also points to overriding of the Transantarctic

Mountains by the east antarctic ice sheet. Higher relative ice levels have been demonstrated also for the Ellsworth Mountains and inferred for the region of the Marie Byrd Land volcanoes. Ice volume increases, however, are difficult to determine because of the lack of information on the age of the glacial features and the uplift of the mountains.

Along with the moraines associated with present glacial drainage there are tills which have a less obvious relationship. Many of these till deposits are included in the Sirius Formation which occurs at elevations up to 2,700 meters and in settings that are unrelated to present drainage. These tills have yielded marine microfossil floras and faunas (Webb et al. 1984). During the 1985-1986 austral summer, wood fragments and other plant debris, including pollen and spores, also were recovered (P.N. Webb and R. A. Askin, personal communication, 1986). The marine microfossils, contained in mud clasts as well as being dispersed in the tills, are dominated by Pliocene taxa and suggest open marine waters, which Webb and others argue were located over East Antarctica during the Pliocene and possibly at several intervals of time earlier in the Cenozoic. This suggests much greater changes in ice volume than previously thought. The plant debris infers temperatures warm enough at 85°S and 1,800 meters elevation (assuming no uplift) to support a sparse vegetation, possibly of tundra type (R.A. Askin, personal communication, 1986). The scale of these variations had not been indicated in the commonly accepted proxy record of antarctic glaciation based on the oxygen isotope record from the oceans.

The absolute dating of glacial events and features, however, remains a major hurdle. Studies of the terrestrial record in West Antarctica have shown the antiquity of glaciation, although the nature and extent of the ice cover remain uncertain. Subglacially-erupted hyaloclastites of Marie Byrd Land volcanoes indicate an age of at least 27 million years (LeMasurier and Rex, 1983). A similar age for early glaciations is provided by results obtained from the Ross Sea during Leg 28 of the Deep Sea Drilling Project (Hayes, Frakes, et al., 1975). At Site 270, glacial sediments indicate that tidewater glaciers calved into the Ross Sea embayment approximately 25 million years ago. Recent paleontological and paleomagnetic data obtained by U.S. scientists from the cores recovered by the New Zealand Antarctic Research Program from McMurdo Sound suggest glacial sedimentation by about 30 million years ago and seven expansions of terrestrial ice into this region (P.N. Webb, personal communication, 1986). On the other hand, the oldest glacial striae, found in the Jones Mountains, can only be dated at about 7 million years or older based on radiometric

age determinations of the overlying basaltic rocks (Rutford et al. 1971).

Meteorite studies

Since 1976 U.S. scientists have searched the blue ice areas* along the Transantarctic Mountains for meteorites. During the first 3 years the U.S. Antarctic Program collaborated with the Japanese Institute of Polar Research in these searches. U.S. investigators have found more than 2,000 fragments.

By ice sheet transport and direct fall, meteorites are concentrated in certain areas of blue ice where ablation is the dominant surface process (Whillans and Cassidy, 1983). The meteorite finds give a new perspective because of petrological and geochemical differences in the antarctic and non-antarctic populations, but the causes and extent of these differences are unclear and debated (Lipschutz and Cassidy, in press). Accepting these differences, the antarctic populations provide not only quantitative estimates of the proportions of different types of meteorites but also estimates of the influx rate because the terrestrial ages can be determined from the decay of cosmogenic nuclides. The oldest age determined so far is 1 million years. This age has important implications for the long-term existence of the east antarctic ice sheet.

The meteorites, despite their age which for the Allan Hills averages 0.3 million years, have suffered very little weathering and are as valuable as modern falls. Apart from these aspects, finds are being made of rare and unusual meteorites, and nearly every season produces another discovery. A lunar sample was recovered in 1981 and is believed to have originated from part of the lunar highlands not sampled by the Apollo or the U.S.S.R. Luna programs. New samples of another unusual group of meteorites, the SNC meteorites, have been found and include one shergottite that contains noble gases and nitrogen with isotopic compositions suggesting derivation from Mars.

Outside the research accomplishments but of major service to the international community on the part of the U.S. scientists are the Symposium on Antarctic Geology and Geophysics held in Madison, Wisconsin, in 1977 and, although less directly concerned with Antarctica, the Sixth Gondwana Symposium held in Columbus, Ohio, in 1985, and the associated publications of the proceedings.

*Blue ice areas occur where glacial movement is stagnated by solid earth ridges. The wind continually ablates less-dense surface layers and exposes the very dense layer, which appears to be a very dense blue.

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References

- Anderson, J.B., C. Brake, E. Domack, N. Meyers and R. Wright. 1983. Development of a polar glacial-marine sedimentation model from Antarctic Quaternary deposits and glaciological information. In *Glacial-Marine Sedimentation*, B. F. Molnia, (ed.), New York, New York: Plenum Press, 233-264.
- Anonymous. 1985. Tectonic map of the Scotia Arc, 1:3,000,000. British Antarctic Survey (Misc) 3. Cambridge, United Kingdom: British Antarctic Survey.
- Antarctic Journal of the United States. 1973. 8(3), 67-141.
- Barrett, P.J., R.J. Baillie, and E.H. Colbert. 1968. Triassic amphibian from Antarctica. *Science*, 161(3840), 460-462.
- Behrendt, J.C., D.J. Drewry, E. Jankowski, and M.S. Grim. 1980. Aeromagnetic and radio-echo ice-sounding measurements show much greater area of the Dufek Intrusion, Antarctica. *Science*, 209, 1014-1017.
- Bentley, C.R. 1983. Crustal structure of Antarctica from geophysical evidence—a review. In *Antarctic Earth Science*, R. L. Oliver, P. R. James, and J. B. Jago, (eds.), Canberra, Australia: Australian Academy of Science.
- Burckle, L.H. 1984. Diatom distribution and paleoceanographic reconstruction in the Southern Ocean—present and last glacial maximum. *Marine Micropaleontology*, 9, 241-261.
- Bushnell, V.C. and C. Craddock. 1969. Geologic map of Antarctica. Antarctic Map Folio Series, Folio 12. New York, New York: American Geographical Society.
- Cande, S.C., E.M. Herron, and B.R. Hall. 1982. The early Cenozoic tectonic history of the southeast Pacific. *Earth Planetary Science Letters*, 57, 63-74.
- Cande, S.C., and J.C. Mutter. 1982. A revised identification of the oldest seafloor spreading anomalies between

- Australia and Antarctica. *Earth Planetary Science Letters*, 58, 151-160.
- Ciesielski, P.F., M.T. Ledbetter and B.B. Ellwood. 1982. The development of Antarctic glaciation and Neogene paleoenvironment of the Maurice Ewing Bank. *Marine Geology*, 46, 1-51.
- Ciesielski, P.F., and F.M. Weaver. 1983. Neogene and Quaternary paleoenvironmental history of Deep Sea Drilling Project Leg 71 sediments, southwest Atlantic Ocean. In *Initial Reports of the Deep Sea Drilling Project, LXXI*, W.J. Ludwig, V.A. Krasheninnikov, et al. (eds.). Washington, D.C.: U.S. Government Printing Office.
- Collinson, J.W., N.R. Kemp, and J.T. Eggert. In press. Comparison of the Gondwana sequence in northern Victoria Land and Tasmania. Proceedings of the Sixth Gondwana Symposium.
- Cooper, A.K., and F.J. Davey. 1985. Episodic rifting of Phanerozoic rocks in the Victoria Land Basin, western Ross Sea, Antarctica. *Science*, 229, 1085-1087.
- Corliss, B.H. 1982. Linkage of North Atlantic and Southern Ocean deep-water circulation during glacial intervals. *Nature*, 298(5873), 458-460.
- Craddock, C. 1972. *Geologic map of Antarctica*. New York, New York: American Geographical Society.
- Craddock, C. 1983. The East Antarctica-West Antarctica boundary between the ice shelves: a review. In *Antarctic Earth Science*, R.L. Oliver, P.R. James and J. B. Jago, (eds.). Canberra: Australian Academy of Science, 94-97.
- Craddock, C. (compiler). In press. *Geologic map of the Circum-Pacific Region, Antarctic sheet, 1:10,000,000, Circum-Pacific Map Project*, Association of Petroleum Geologists, Tulsa.
- Craddock, C., T.W. Bastien, R.H. Rutford, and J.J. Anderson. 1965. *Glossopteris* discovered in West Antarctica. *Science*, 148, 634-637.
- Dalziel, I.W.D. 1981. Back-arc extension in the Southern Andes: a review and critical reappraisal. *Philosophical Transactions of the Royal Society, London*, A300, 319-335.
- Dalziel, I.W.D. 1984. Tectonic evolution of a fore-arc terrane, Southern Scotia Ridge, Antarctica. *Geological Society of America Special Paper*, 200, 32 pp.
- Dalziel, I.W.D. 1985. Collision and cordilleran orogenesis: an Andean perspective. In *Collision Tectonics*, M.P. Coward and A.C. Reis, (eds.). Geological Society of London Special Paper, 19, 389-404.
- Dalziel, I.W.D., and D.H. Elliot. 1982. West Antarctica: problem child of Gondwanaland. *Tectonics*, 1(1), 3-19.
- Dalziel, I.W.D., S.W. Garrett, A.M. Grunow, R.J. Pankhurst, B.C. Storey, and W.R. Vennum. In press. The Ellsworth-Whitmore crustal block: its role in the tectonic evolution of West Antarctica. Proceedings of the Sixth Gondwana Symposium.
- Denton, G.H., M.L. Prentice, D.E. Kellogg and T.B. Kellogg. 1984. Late Tertiary history of the antarctic ice sheet: evidence from the dry valleys. *Geology*, 12(5), 203-267.
- Dow, R.L. 1978. Radiolarian distribution and the Late Pleistocene history of the southeastern Indian Ocean. *Marine Micropaleontology*, 3, 203-227.
- Eittreim, S.L., and G.L. Smith. In press. Seismic sequences and their distribution on the Wilkes Land margin. In *Antarctic Continental Margin Studies*, S.L. Eittreim, A. Cooper, M. Hampton, and F. Davey, (eds.). Circum-Pacific Council for Energy and Mineral Resources Earth Science Series.
- Elliot, D.H. 1975. Tectonics of Antarctica: A review. *American Journal of Science*, 275(A), 45-106.
- Elliot, D.H., E.H. Colbert, W.J. Breed, J.A. Jensen, and J.S. Powell. 1970. Triassic tetrapods from Antarctica: evidence for continental drift. *Science*, 169(3951), 1197-1201.
- Goodell, H.G., R. Houtz, M. Ewing, D.E. Hayes, B. Naini, R.J. Echols, J.P. Kennett, and J.G. Donahue. 1973. Marine sediments of the Southern Oceans. Antarctic Map Folio Series, Folio 17. New York: American Geographical Society.
- Grunow, A., I.W.D. Dalziel, and D.V. Kent. In press. Ellsworth Mountains-Whitmore Mountains crustal block, western Antarctica: New paleomagnetic results and their tectonic significance. Proceedings of the Sixth Gondwana Symposium.
- Hammer, W.R. and J.W. Cosgriff. 1981. *Myosaurus gracilis*, an anomodont reptile from the Lower Triassic of Antarctica and South Africa. *Journal of Paleontology*, 55, 410-424.
- Hayes, D.E. 1972. *Antarctic Oceanology II*, Antarctic Research Series, Volume 19. Washington, D.C.: American Geophysical Union.
- Hayes, D.E., and F.J. Davey. 1975. Geophysical study of the Ross Sea, Antarctica. In *Initial Reports of the Deep Sea Drilling Project 28*, D.E. Hayes, and L.A. Frakes, et al. Washington, D.C.: U.S. Government Printing Office, 887-908.
- Hayes, D.E., L.A. Frakes, et al. (eds.), 1975. *Initial Reports of the Deep Sea Drilling Project, 28*. Washington, D.C.: U.S. Government Printing Office.
- Hays, J.D., J. Imbrie, and N.J. Shackleton. 1976a. Variations in the Earth's orbit: pacemaker of the ice ages. *Science*, 194, 1121-1132.
- Hays, J.D., J.A. Lozano, N. Shackleton, and G. Irving. 1976b. Reconstruction of the Atlantic and western Indian Ocean sectors of the 18,000 years B.P. Antarctic Ocean. In *Investigation of Late Quaternary Paleooceanography and Paleoclimatology*, R.M. Cline and J.D. Hays, (eds.). Geological Society of America Memoir, 145, 337-374.
- Hays, J.D., and N.D. Opdyke. 1967. Antarctic radiolaria, magnetic reversals, and climatic change. *Science*, 158(3804), 1001-1011.
- Heezen, B.C., M. Tharp, and C.R. Bentley. 1973. Morphology of the earth in the Antarctic and Subantarctic. Antarctic Map Folio Series, Folio 16. New York: American Geographical Society.
- Heirtzler, J.R. 1971. The evolution of the Southern Oceans. In *Research in the Antarctic*, L.O. Quam (ed.). American Association for the Advancement of Science, Washington, D.C., p. 667-684.
- Houtz, R.E., and F.J. Davey. 1973. Seismic profiles and sonobuoy measurements in the Ross Sea, Antarctica. *Journal of Geophysical Research*, 78, 3448-3468.
- Keany, J., M.T. Ledbetter, N. Watkins, and T.-C. Huang. 1976. Diachronous deposition of ice-rafted debris in sub-Antarctic deep-sea sediments. *Geological Society of America Bulletin*, 87, 873-882.
- Kennett, J.P. 1978a. The development of planktonic biogeography in the Southern Ocean during the Cenozoic. *Marine Micropaleontology*, 3, 301-345.
- Kennett, J.P. 1978b. Cenozoic evolution of antarctic glaciation, the circum-antarctic ocean, and their impact on global paleoceanography. *Journal of Geophysical Research*, 82, 3843-3860.
- Kennett, J.P., and N.D. Watkins. 1976. Regional deep-sea dynamic processes recorded by late Cenozoic sediments of the southeastern Indian Ocean. *Geological Society of America Bulletin*, 87, 321-339.
- Kim, Y., L.D. McGinnis and R.H. Bowen. 1986. The Victoria Land Basin: part of

- an extended crustal complex between East and West Antarctica. In *Reflection Seismology: The Continental Crust*, M. Barazangi and L. Brown (eds.) Geodynamics Series, 14. Washington, D.C.: American Geophysical Union.
- Kitching, J.W., J.W. Collinson, D.H. Elliot, and E.H. Colbert. 1972. Lystrosaurus zone (Triassic) fauna from Antarctica. *Science*, 175(4021), 524-527.
- LaBrecque, J.L., and P.F. Barker. 1981. The age of the Weddell Basin. *Nature*, 290(5806), 489-492.
- Lawver, L.A., J.G. Sclater, and L. Meinke. 1985. Mesozoic and Cenozoic reconstructions of the South Atlantic. In *Geophysics of the Polar Regions*, E.S. Husebye, G.L. Johnson, and Y. Kristoffersen, (eds.). *Tectonophysics*, 114, 233-254.
- Ledbetter, M.T. and P.F. Ciesielski. 1986. Post-Miocene disconformities and paleo-oceanography in the Atlantic sector of the Southern Ocean. *Paleogeography, Palaeoclimatology, Palaeoecology*, 52, 185-214.
- LeMasurier, W.E. and D.C. Rex. 1983. Rates of uplift and the scale of ice level instabilities recorded by volcanic rocks in Marie Byrd Land, West Antarctica. In *Antarctic Earth Science*, R.L. Oliver, P.R. James and J.B. Jago, (eds.). Canberra, Australia: Australian Academy of Science.
- Lipschutz, M.E. and W.A. Cassidy. In press. Antarctic meteorites: a progress report. *EOS*.
- Macellari, C.E. 1986. Late Campanian-Maastrichtian ammonite fauna from Seymour Island (Antarctic Peninsula). *Journal of Paleontology*, Paleontological Society Memoir 18, 55 pp.
- Malmgren, B., and J.P. Kennett. 1972. Biometric analysis of phenotypic variation: *Globigerina pachyderma* (Ehrenberg) in the South Pacific Ocean. *Micropaleontology*, 18(2), 241-248.
- Osborn, N.I., P.F. Ciesielski, and M.T. Ledbetter. 1983. Disconformities and paleoceanography in the southeast Indian Ocean during the last 5.4 million years. *Geological Society of America Bulletin*, 94, 1345-1358.
- Rooney, S.T., D.D. Blankenship, and C.R. Bentley. In press. Seismic refraction measurements of crustal structure in West Antarctica. Proceedings of the Sixth Gondwana Symposium.
- Rowley, P.D., W.R. Vennum, K.S. Kellogg, T.S. Laudon, P.E. Carrara, J.M. Boyles, and M.R.A. Thomson. 1983. Geology and plate tectonic setting of the Orville Coast and eastern Ellsworth Land, Antarctica. In *Antarctic Earth Science*, R.L. Oliver, P.R. James, and J.B. Jago, (eds.). Canberra, Australia: Australian Academy of Science.
- Rutford, R.H., C. Craddock, C.M. White, and R.L. Armstrong. 1972. Tertiary glaciation in Antarctica. In *Antarctic Geology and Geophysics*, R.J. Adie, (ed.). Oslo, Norway: Universitetsforlaget.
- Schopf, J.M. 1969. Ellsworth Mountains: position in West Antarctica due to sea-floor spreading. *Science*, 164, 63-66.
- Schopf, J.M. 1982. Forms and Facies of *Vertebraria* in relation to Gondwana coal. In *Geology of the Central Transantarctic Mountains*, M.D. Turner and J.F. Spletstoesser, (eds.). Antarctic Research Series, Vol. 36. Washington, D.C.: American Geophysical Union.
- Shackleton, N.J. and J.P. Kennett. 1975. Paleotemperature history of the Cenozoic and the initiation of antarctic glaciation: Oxygen and carbon isotope analyses in DSDP sites 277, 279, and 281. In *Initial Reports of the Deep Sea Drilling Project, XXIX*, J.P. Kennett and R.E. Mowez, et al (eds.). Washington, D.C.: U.S. Government Printing Office.
- Sporli, K.B., and C. Craddock. 1981. Geology of the Ruppert Coast, Marie Byrd Land, Antarctica. In *Gondwana Five*, M. M. Creswell and P. Vella, (eds.). Rotterdam, the Netherlands: A.A. Balkema.
- Storey, B.C. and I.W.D. Dalziel. In press. Aspects of the structural and tectonic history of the Ellsworth Mountains-Thiel Mountains ridge, West Antarctica. Proceedings of the Sixth Gondwana Symposium.
- Stubblefield, S.P. and T.N. Taylor. In press. Fungal induced wood decay in *Araucarioxylon* from the Triassic of Antarctica. Proceedings of the Sixth Gondwana Symposium.
- Stuiver, M., G.H. Denton, T.J. Hughes and J.L. Fastook. 1981. History of the marine ice sheet in West Antarctica during the last glaciation: a working hypothesis. In *The Last Great Ice Sheets*, G.H. Denton and T.J. Hughes, (eds.). New York, New York: Wiley-Interscience.
- Watkins, N.D., J. Keany, M.T. Ledbetter, and T-C. Huang. 1974. Antarctic glacial history from analysis of ice-rafted deposits in marine sediments: new model and initial tests. *Science*, 186, 533-536.
- Watkins, N.S., M.T. Ledbetter, and T-C. Huang. 1982. Antarctic glacial history using spatial and temporal variations of ice-rafted debris in abyssal sediments of the Southern Ocean. In *Antarctic Geoscience*, C. Craddock, (ed.). University of Wisconsin Press, Madison, Wisconsin, 1013-1016.
- Watkins, N.D., and J.P. Kennett. 1972. Regional sedimentary disconformities and upper Cenozoic changes in bottom water velocities between Australia and Antarctica. In *Antarctic Oceanology II: The Australian-New Zealand Sector*, D.E. Hayes, (ed.). Antarctic Research Series, Vol. 19. Washington, D.C.: American Geophysical Union.
- Watts, D.R., and A.M. Bramall. 1981. Paleomagnetic evidence for a displaced terrain in West Antarctica. *Nature*, 295, 315-317.
- Webb, P.N., D.M. Harwood, B.C. McKelvey, J.H. Mercer, and L.D. Stott. 1984. Cenozoic marine sedimentation and ice-volume variation on the East Antarctic craton. *Geology*, 12(5), 287-291.
- Webers, G.F. 1972. Unusual Upper Cambrian fauna from West Antarctica. In *Antarctic Geology and Geophysics*, R.J. Adie, (ed.). Oslo, Norway: Universitetsforlaget.
- Webers, G.F., J. Pojeta, and E.L. Yochelson. In press. Cambrian molluscs from the Minaret Formation, Ellsworth Mountains, West Antarctica. In *Geology and Paleontology of the Ellsworth Mountains*, Memoir, C. Craddock, J.F. Spletstoesser and G.F. Webers, (eds.). Geological Society of America.
- Weissel, J.K., and D.E. Hayes. 1972. Magnetic anomalies in the southeast Indian Ocean. In *Antarctic Oceanology II: the Australian-New Zealand sector*, D.E. Hayes (ed.), Antarctic Research Series, Volume 19. Washington, D.C.: American Geophysical Union, p. 165-196.
- Weissel, J.K., D.E. Hayes, and E.M. Herron. 1977. Plate tectonic synthesis: displacements between Australia, New Zealand, and Antarctica since the Late Cretaceous. *Marine Geology*, 25, 231-277.
- Whillans, I.M., and W.A. Cassidy. 1983. Catch a falling star: meteorites and old ice. *Science*, 222,(4619), 55-57.
- Williams, D.F., N. Healy-Williams, and P. Leschak. 1985a. Dissolution and water-mass patterns in the southeast Indian Ocean. Part I: Evidence from recent to late Holocene foraminiferal assemblages. *Geological Society of America Bulletin*, 96(2), 176-189.
- Williams, D.F., D. Gribble, N. Healy-Williams, and P. Leschak. 1985b. Dissolution and water-mass patterns in the southeast Indian Ocean. Part II: The Pleistocene record from Brunhes to Matuyama age sediments. *Geological*

Woodburne, M.O., and W.J. Zinsmeister. 1982. Fossil land mammal from Antarctica. *Science*, 218, 284-286.

Woodburne, M.O. and W.J. Zinsmeister. 1984. The first land mammal from Antarctica and its biogeographic implications. *Journal of Paleontology*, 58(4), 913-948.

Wright, R., J.B. Anderson, and P.P. Fisco. 1983. Distribution and association of sediment gravity flow deposits and glacial/glacial-marine sediments around the continental margin of Antarctica. In *Glacial Marine Sedimentation*, B.F. Molnia, [ed.]. New York: New York: Plenum Press, 265-300.

Zinsmeister, W.J. 1979. Biogeographic significance of the Late Mesozoic and Early Tertiary molluscan faunas of Seymour Island (Antarctic Peninsula) to the final breakup of Gondwanaland. In *Historical Biogeography, Plate Tectonics, and the Changing Environment*, (Proceedings of the 37th Biological Colloquium), J. Grey and A.J. Boucot, (eds.). Oregon State University Press.

Zinsmeister, W.J. 1984. Geology and paleontology of Seymour Island, Antarctic Peninsula. *Antarctic Journal of the United States*, 19(2), 1-5.

Glaciology

Antarctic glaciology has advanced dramatically since the International Geophysical Year (IGY). Perhaps the most striking technological advance was the development of radar sounding of ice thickness, particularly from the air. Its importance to glaciology is comparable to the importance to oceanography of the development of the sonic echo sounder that replaced the lead line. During the IGY an individual sounding of the ice sheet by seismic shooting took 2 or 3 hours and was followed a day later by another sounding several kilometers away. Radar sounding, in contrast, takes less than 50 microseconds for an individual measurement and yields a continuous profile of ice thickness at aircraft flying speed.

In January 1958, Amory H. Waite of the U.S. Signal Corps conducted the first successful radar sounding of an ice sheet on ice up to 600 meters thick near Wilkes Station, East Antarctica. Following his lead, researchers at the Scott Polar Research Institute in England, the University of Wisconsin in the United States, and the Technical University of Denmark developed this technique further. By the middle 1960's, scientists routinely used

radar sounding on the surface and from the air to map the subglacial topography and to study ice characteristics.

Between 1967 and 1979 a cooperative American-British-Danish radar sounding program from U.S. ski-equipped Hercules (LC-130) airplanes was conducted over 50 percent of Antarctica. An example of how radar sounding improved knowledge of the subglacial topography of the continent is shown in figure 1. The two maps in this figure show the subglacial topography of eastern Wilkes Land based on two different data sets—one from IGY measurements and the other from the radar flight program.

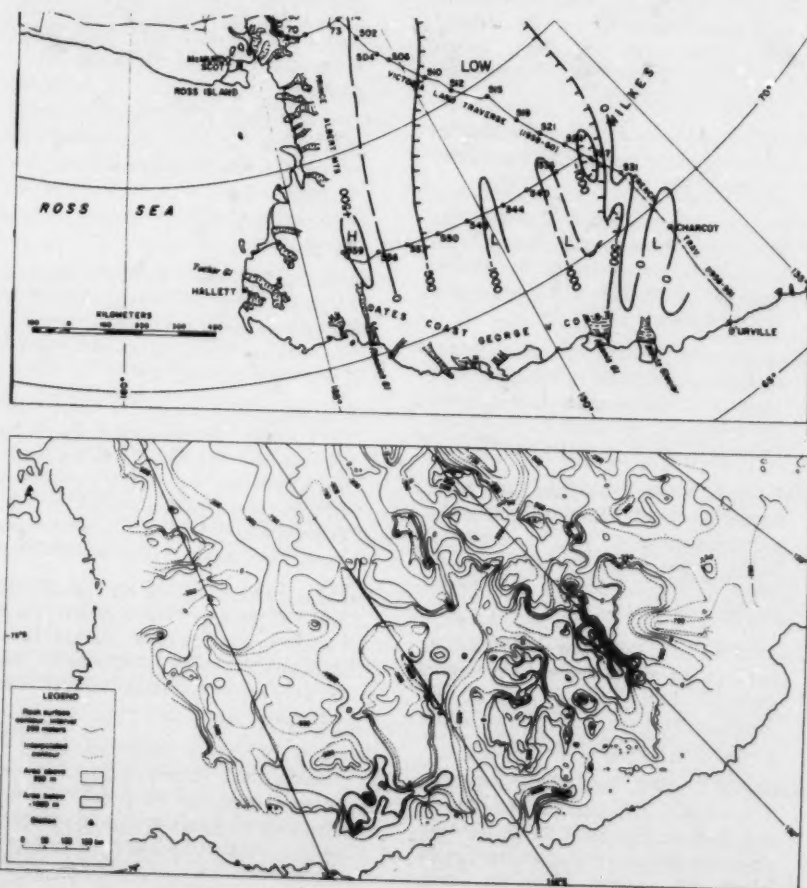
Radar sounding yields much more information than simply the ice thickness (Bogorodsky, et al., 1985). Of particular interest are the many internal layers in ice sheets of Antarctica and Greenland. These internal layers are associated with small density changes, presumably depositional or diagenetic, and with changes in electrical conductivity related to volcanic ash fallout. The internal reflections provide isochrons* within the ice sheet that can be invaluable in studying how ice flow varies in time

and space. Changes in the character of the basal echo have proved useful in delineating what appear to be lakes beneath the ice sheet where the ice is thick enough for its bed to be at the melting point. Characteristic signals from features within the ice, such as bottom crevasses on ice shelves, can be identified on successive flight tracks and, consequently, provide precise ice movement paths. Crevasse near the surface is a particular feature of the giant ice streams that glaciologists now know transport most of the ice from the antarctic interior; these ice streams produce a striking difference in the radargram that has been recorded over them and that makes it possible to identify ice streams even when the crevasses are buried and invisible (figure 2).

The advent of radar sounding has not, however, diminished the usefulness of seismic sounding. On floating ice shelves, whose importance to the dynamic balance

*"Isochrons" are lines connecting points of equal age.

Figure 1. Two maps of subglacial topography in Wilkes Land, East Antarctica. The upper map is from seismic and gravity soundings on oversnow traverses during the IGY (Crary, 1963). The lower is from airborne radar sounding (Steed and Drewry, 1982).



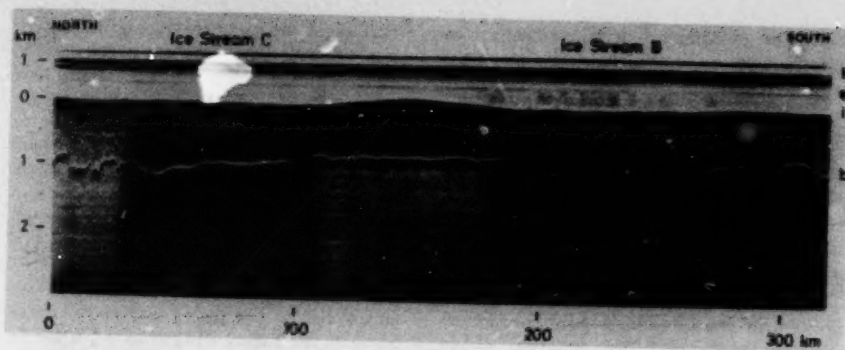


Figure 2. Radargram showing a profile across two West Antarctic ice streams. The ice-bottom reflection is at about 1 kilometer. Note the scattered returns from near-surface crevasses that extend from top to bottom of the record under the ice streams. (From Rose, 1979).

of the ice sheet becomes ever more apparent, seismic sounding can be combined with radar sounding to give both ice thickness and water depth below the ice (radar waves do not penetrate water). In the mid-1970's, as part of the Ross Ice Shelf project (RISP) (one of several detailed surveys of selected areas supported by the United States), a 5-year project called the Ross Ice Shelf Geophysical and Glaciological Survey (RIGGS) was conducted. This program, which used Twin Otter airplanes, included among its many measurements (Bentley, 1984) seismic soundings of the water depth; these soundings were then combined with oceanic soundings in the open Ross Sea and radar soundings of the inland ice of West Antarctica. These data yielded a subglacial morphology map (figure 3) that shows no indication in the subglacial morphology of the outer edge of the ice shelf or of the boundary between the grounded and floating ice. This fact dramatizes the impermanence of the glacial boundaries.

At one RISP site (J-9), oceanographers and biologists used first a flame-jet drill and then a hot water drill to gain access to the ocean beneath the ice shelf. Nearby at the same site, Soviet glaciologists obtained an ice core by using antifreeze-thermal drilling through the shelf (Zotikov, et al., 1980). This core included 6 meters of sea ice that had frozen to the shelf bottom. Although it had previously been proposed that basal freezing occurs beneath parts of the ice shelf, this was the first time that sea ice was observed on the base of the Ross Ice Shelf.

Another technological revolution in glaciology resulted from the development of Doppler-satellite positioning. During the IGY, the velocity of ice movement could only be measured close to rock outcrops, which are few in Antarctica. Satellite techniques now have made possible accurate positioning to a few meters in just a few hours. Measurements repeated at the same spot on the ice after a suitable time period (a few months to a few years,

depending on the speed of ice movement), yield precise velocities. One of the accomplishments of RIGGS was the production in this way of a velocity-vector map of the ice shelf (figure 4).

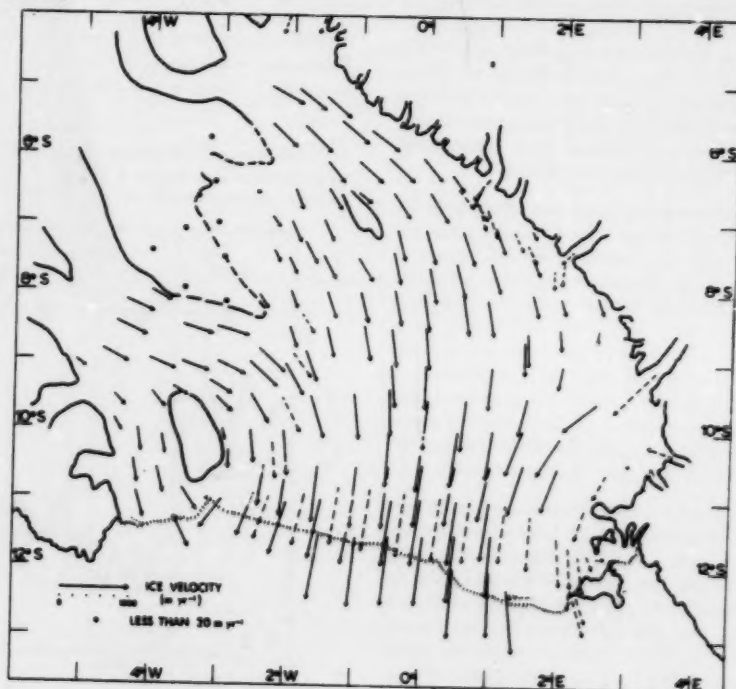
Because glaciologists are now able to map ice thickness and ice movement in detail, they can test some rather dramatic theories about the dynamic behavior of the ice sheet, particularly that of West Antarctica. Many theories on ice sheet growth, surging, and similar behavior exist, but not until Weertman (1976) wrote about "glaciology's grand unsolved problem" did the glaciological community focus its attention on the west antarctic ice sheet. Stimulated by writings of T.J. Hughes,



Figure 3. Map of the subglacial and submarine topography in the entire Ross Embayment. The contour interval changes from 50 meters under the Ross Sea and Ross Ice Shelf to 250 meters under the west antarctic inland ice. (From Bentley and Jezek, 1981).

Weertman challenged glaciologists to confront the physics of this marine ice sheet, whose base over much of its area was 0.5 to 1 kilometer below sea level. How does it remain in existence? Is it growing or shrinking at this time? Could it disintegrate in hundreds of years?

Figure 4. Map of ice velocity vectors on the Ross Ice Shelf. Values from RIGGS measurements are depicted by solid arrows; dashed arrows are from earlier measurements. (From Thomas et al, 1984).



Weertman also asked why the ice streams that drain most of the interior west antarctic ice into the Ross and other ice shelves move so fast. The latter question is a key to the stability of the ice sheet, and preliminary results of recent investigations relating to it are now being published. Glaciologists suggested that a thin water layer beneath ice streams was responsible for their swift motion. However, seismic sounding (Blankenship et al, in press) has shown that beneath one ice stream a subglacial till layer that is several meters thick is a likely mechanism for the fast "sliding." Another intriguing aspect of ice-stream behavior is that ice stream C on the Siple Coast, which clearly was once one of the major ice streams, has stopped its rapid motion, perhaps within the last few centuries.

To understand ice-sheet behavior the rate of snow accumulation on the surface of the ice sheet must be known. Because that rate can differ from year to year, an average over several years is desirable. During the IGY, scientists determined accumulation rates by studying the stratigraphic features in the walls of snow pits and in ice cores. The idea was to identify annual layers by the cyclic variations in density, grain size and type, hardness, and other characteristics. The success of this method depended heavily on the skill and experience of the observers and was subject to serious errors in the cold, low-precipitation interior regions of Antarctica. An important development for mass balance studies, therefore, was the discovery that discrete radioactive-fallout horizons, stemming from atmospheric hydrogen-bomb tests, occur all over the ice sheets. The most distinctive marks occur during the austral summers of 1954-1955 and 1964-1965. These horizons are easily identified in ice cores and provide excellent means of determining mean accumulation rates over a decade or more (depending on when the core was collected).

Measurements of accumulation rates by this means were included in the program of RIGGS; the resulting map (Clausen, et al., 1979) is the only one of the Antarctic that provides accurate values covering the surface of a large region. Many such measurements have also been made along traverses on the high interior plateau of East Antarctica; these measurements led to a drastic lowering of estimates of mean accumulation rates relative to those made from IGY and post-IGY pit studies.

The great strides that have been made in measuring snow accumulation rates, ice thicknesses, and velocities have greatly improved the ability of glaciologists to determine the net mass balance of the ice sheet, i.e., the difference between mass input in the form of snowfall and mass output in the form of melting and calving

of icebergs. Although definitive conclusions cannot yet be drawn about the ice sheets as a whole, analyses gradually have accumulated on individual drainage basins within the ice sheet. Together, they strongly suggest that the amount of ice in the Antarctic is not decreasing and may be growing slowly. A recent workshop study on the effect of glaciers and ice sheets on sea level (Polar Research Board, 1985) concluded that at present the best estimate of average net growth of the ice sheet amounts to 20 millimeters (plus or minus 20 millimeters) of ice per year or an equivalent to a sea-level lowering of 0.6 millimeters (plus or minus 0.6 millimeters) per year.

Another impressive leap forward in our understanding of polar ice sheets came from deep ice-core drilling from 1966 to 1968. During those 3 years the ice sheets in Greenland and Antarctica were cored through to bedrock; consequently, more ice core than the world had ever had before was available for immediate and archival study. The U.S. Army Cold Regions Research and Engineering Laboratories (CRREL) fielded engineering and scientific teams that recovered 1,375 meters of core from Camp Century, Greenland, in 1966 and 2 years later (in 1968) recovered 2,164 meters of core at Byrd Station in West Antarctica. This was one of the major engineering and logistics accomplishments of the U.S. glaciological program, considering the remote sites for the drilling, the hostile environment, and the difficulty of drilling in ice.

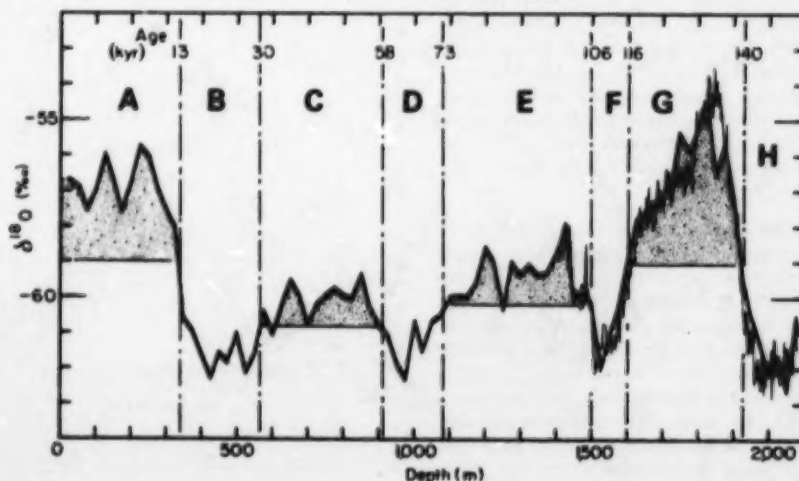
No aspect of polar glaciology has produced more spectacular results than the analyses of these deep ice cores and those that have been retrieved since the 1960's. There are now five deep core holes that penetrate at least into ice that fell on the

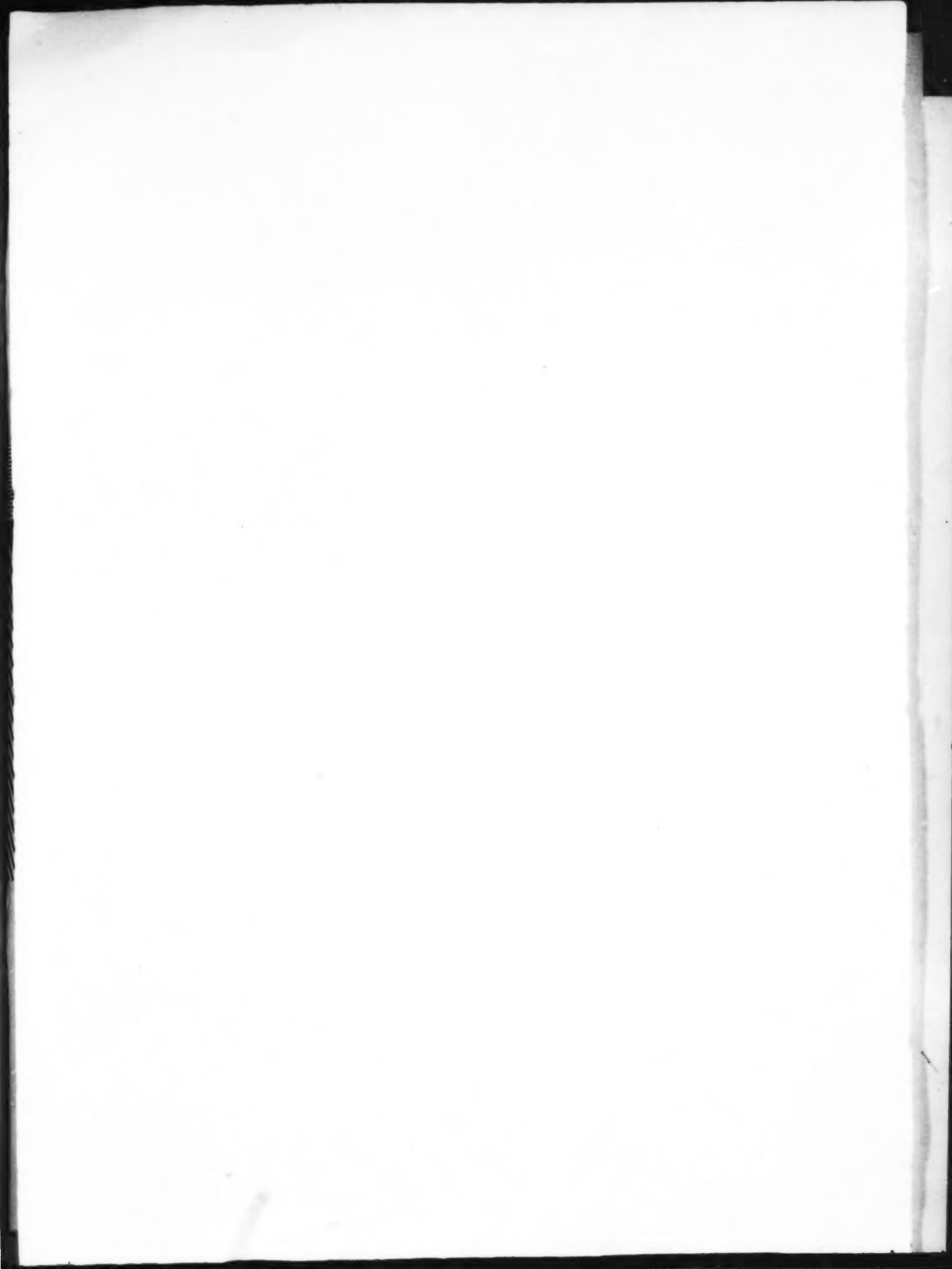
surface of the ice sheet during the last ice age. We will consider three parameters in particular—the oxygen-isotope ratios, total gas content, and carbon-dioxide levels. Oxygen-isotope ratios (oxygen-18 to oxygen-16), which depend on the ambient temperature at the time of precipitation, show strikingly the climatic transition from the last ice age to the present interglacial. One core penetrated both the last glacial epoch and the last interglacial and into the top of the ice deposited in the previous glacial epoch. The record in that core, from the Soviet station Vostok in central East Antarctica, shows that the present Holocene period was preceded by a long glacial period marked by two relatively warm interstadial** (figure 5). The well-marked last interglacial was significantly warmer than the Holocene, and the end of the previous glacial was similar to the last glacial maximum.

Oxygen-isotope changes may be interpreted in terms of paleotemperature, but the cause of past temperature changes is not only climatic. If the surface elevation of the ice sheet on which the snow fell changed with time, the temperature would have changed accordingly, even without climatic change. The amount of total gas trapped as gas bubbles in the ice depends upon the atmospheric pressure at the time the bubbles were formed by the compaction of porous snow and, therefore, upon the elevation. By measuring both the oxygen-isotope ratio and the total gas content, scientists can separate the two effects. The data suggest that the ice surface of central West Antarctica was no higher than it is today and perhaps even 100 or 200 meters lower during the last glacial period (Raynaud and Whillans, 1982).

**"Interstade" refers to a warmer substage of a glacial stage.

Figure 5. Oxygen-18 versus depth in an ice core from Vostok, in central East Antarctica. An approximate age scale is given at the top of the figure. More negative values of isotopic oxygen-18 mean colder temperatures. (From Lorius et al, 1985).





Weather at U.S. stations

Feature	February 1986				March 1986				April 1986			
	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole
Average temperature (°C)	- 6.6	3.9	-18.2	-36.1	-16.5	3.3	-21.6	-52.0	-20.3	- 0.4	-25.5	-58.2
Temperature maximum (°C) (date)	1.5 (3)	9.0 (5)	- 7.9 (24)	-25.5 (23)	- 2.6 (1)	7.3 (20)	- 6.0 (2)	-35.4 (4)	- 5.8 (30)	6.5 (25)	-14.2 (4)	-40.7 (14)
Temperature minimum (°C) (date)	-16.3 (25)	- 1.2 (8)	-34.7 (9)	-46.8 (28)	-31.4 (30)	- 2.6 (9)	-32.4 (25)	-69.5 (27)	-39.9 (15)	- 5.5 (11)	-40.7 (20)	-65.4 (29)
Average station pressure (mb)	994.4	984.0	870.6	694.6	993.8	986.7	870.7	685.1	983.0	987.2	863.2	681.7
Pressure maximum (mb) (date)	1003.5 (22)	1009.1 (27)	880.0 (25)	704.5 (24)	1007.5 (17)	1017.2 (25)	885.0 (4)	702.2 (17)	993.4 (18)	1006.9 (13)	873.3 (25)	693.9 (7)
Pressure minimum (mb) (date)	981.3 (1)	964.2 (17)	864.8 (14)	683.7 (2)	965.8 (31)	952.1 (30)	858.5 (23)	667.9 (30)	967.9 (1)	964.0 (8)	844.5 (1)	669.5 (15)
Snowfall (mm)	7.6	2.5	0.0	TRACE	3.8	1.8	0.0	TRACE	17.0	12.5	0.0	TRACE
Prevailing wind direction	095°	360°	175°	010°	090°	120°	184°	360°	070°	030°	190°	360°
Average wind (m/sec)	7.0	8.6	9.6	9.4	5.1	6.8	10.6	20.2	5.7	7.5	8.8	9.0
Fastest wind (m/sec) (date)	21.9 160° (25)	26.8 080° (3)	23.0 180° (21)	31.1 023° (20)	25.9 200° (25)	31.9 360° (27)	30.0 180° (12)	39.2 360° (30)	29.1 150° (30)	27.8 060° (28)	28.3 350° (5)	32.2 338° (4& 11)
Average sky cover	5.7	7/10	8/10	0.6	6.7	8/10	9/10	0.4	6.8	8/10	6/10	0.5
Number clear days	8.0	12.8	2.5	7.0	5.0	5.5	2.0	8.0	4.0	6.9	7.0	10.0
Number partly cloudy days	14.0	2.7	4.5	10.0	11.0	5.6	0.2	9.0	5.0	6.4	3.2	13.0
Number cloudy days	6.0	11.5	14.0	11.0	15.0	20.0	13.7	14.0	21.0	16.7	16.0	7.0
Number days with visibility less than 0.4 km.	0.0	---	7.0	0.4	1.4	---	9.0	3.8	1.5	---	3.7	1.0

Prepared from information received by teletype from the stations. Locations: McMurdo 77°51'S 166°40'E, Palmer 64°46'S 64°3'W, Siple 75°55'S 83°55'W, Amundsen-Scott South Pole 90°S. Elevations: McMurdo sea level, Siple 1054 meters, Amundsen-Scott South Pole 2835 meters. For prior data and daily logs, contact National Climate Center, Asheville, North Carolina 28801.

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Measurement of the carbon-dioxide concentration in the gas bubbles and comparison with the oxygen-isotope record have shown that carbon-dioxide changes are associated with climatic changes. Levels in recent but pre-industrial times were some 40 percent higher than they were during the last glacial epoch. Naturally, it would be of great interest to know whether a cause and effect relationship was apparent between the changes in the amount of ice and the variation in the levels of atmospheric carbon dioxide. Intriguingly, detailed studies, accurate to a few 100 years in relative time, have been unable to distinguish any time lead of one variation over the other (Stauffer et al, 1984). Although this result does not reveal which change (if either) causes the other, it does show that response times in the carbon-dioxide-climate system are very short.

A quantum leap in our understanding of the antarctic ice sheet has occurred since the IGY. As technology provides new tools and physics provides new techniques, more data will be available to improve our understanding of the dynamics of the ice and its historical development. With satellite altimetry, mapping of the surface topography can be conducted with such precision as to measure fluctuations in ice sheet volume, and further deep ice-core drilling could well provide a climatic record for more than a million years.

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Richard L. Cameron, glaciologist, and Charles R. Bentley, Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706.

References

Bentley, C.R., 1984. The Ross Ice Shelf Geophysical and Glaciological Survey (RIGGS): Introduction and summary of measurements performed. In *Antarctic Research Series*, Vol. 42 (C.R. Bentley and D.E. Hayes, eds.). Washington, D.C.: American Geophysical Union.

Bentley, C.R., and K.C. Jezek, 1981. RISS, RISP, and RIGGS: Post-IGY glaciological investigations of the Ross Ice Shelf in the U.S. program. *Journal of the Royal Society of New Zealand*, vol. 11, no. 4, p. 355-372.

Blankenship, D.D., S.T. Rooney, C.R. Bentley, and R.B. Alley, in press. Seismic measurements reveal a saturated, porous layer beneath an active Antarctic ice stream. *Nature*.

Bogorodsky, V.V., C.R. Bentley, and P.E. Gudmandsen, 1985. *Radioglaciology*. Reidel Publishing Company.

Clausen, H.B., W. Dansgaard, J. Nielson, and J.W. Clough, 1979. The surface accumulation on the Ross Ice Shelf. *Antarctic Journal of the U.S.*, vol. XIV, no. 5, p. 68-72.

Crary, A.P. 1963. Results of U.S. traverses in East Antarctica, 1958-62. *IGY Glaciological Report Series* (New York, IGY World Data Center A, Glaciology, American Geographical Society), no. 7.

Lorius, C., J. Jouzel, C. Ritz, L. Merlivat, N.I. Barkov, Y.S. Korotkevich, and V.M. Kotlyakov, 1985. A 150,000-year climatic record from Antarctic ice. *Nature*, vol. 316, no. 6029, p. 591-596.

Polar Research Board, National Academy of Sciences, 1985. *Glaciers, Ice Sheets, and Sea Level: Effects of Carbon Dioxide-Induced Climatic Change*. Washington, D.C.: National Academy Press.

Raynaud, D., and I.M. Whillans, 1982. Air content of the Byrd core and past changes in the West Antarctic ice sheet. *Annals of Glaciology*, vol. 3, p. 269-273.

Rose, K.E. 1979. Characteristics of ice flow in Marie Byrd Land, Antarctica. *Journal of Glaciology*, vol. 24, no. 90, p. 63-75.

Stauffer, B., H. Hofer, H. Oeschger, J. Schwander, and U. Siegenthaler, 1984. Atmospheric carbon dioxide concentration during the last glaciation. *Annals of Glaciology*, vol. 5, p. 160-164.

Steeds, R.H.N., and D.J. Drewry, 1982. Radio echo sounding investigations of Wilkes Land, Antarctica. In *Antarctic Geoscience*, C. Craddock (ed.). Madison, Wisconsin: University of Wisconsin Press.

Thomas, R.H., D.R. MacAyeal, D.H. Eilers, and D.R. Gaylord, 1984. Glaciological studies on the Ross Ice Shelf, Antarctica, 1973-1978. In *Antarctic Research Series*, Vol. 42 C.R. Bentley and D.E. Hayes, (eds). Washington, D.C.: American Geophysical Union.

Weertman, J. 1976. Glaciology's grand unsolved problem. *Nature*, vol. 260, no. 5549, p. 284-286.

Zotikov, I.A., V.S. Zagorodnov, and J.V. Raikovski, 1980. Core drilling through the Ross Ice Shelf (Antarctica) confirmed basal freezing. *Science*, vol. 207 (4438), p. 1463-1465.

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Early season flights bring scientists to Antarctica to study ozone depletion

In August 1986 12 scientists, comprising four research teams, flew to McMurdo Station on early season flights to study the alarming annual deviations in the ozone

A researcher cleans and checks equipment on top of the clean air facility at Amundsen-Scott South Pole Station. At this observatory scientists monitor various atmospheric parameters and measure their effect on global climate. These baseline data, taken far from pollution sources, are used to determine whether gases or particulates introduced into the atmosphere by natural causes or human activities significantly affect climate.

NSF photo by Ann Hawthorne.



layer above Antarctica. Ozone, a form of oxygen, exists throughout the atmosphere in small amounts but is principally concentrated in a layer about 15 miles above the Earth. It is critical to life on Earth because it screens out much solar ultraviolet radiation that causes skin cancer and could harm plants.

Two papers in the 19 June issue of the British journal *Nature*—one by U.S. researchers and one by British scientists who have been recording ozone levels over Halley Bay in the eastern Weddell Sea region—reported that since 1975 about a 50-percent decrease in the total amount of ozone above Antarctica has occurred each austral spring. The data are supported by National Aeronautics and Space Administration (NASA) satellite data which show that the spring depletion extends over much of Antarctica, creating a "hole in the ozone" about the size of the United States.

One puzzling aspect of this problem is that the dramatic deviations apparently occur only during the austral spring, from mid-August to late October. The largest rate of depletion occurs in September. Scientists have suggested various theories to explain the seasonal phenomenon, including high solar activity, dynamic forces in the polar atmosphere, and manmade or natural chemical triggers.

The four teams working in Antarctica are from the University of Wyoming, the State University of New York at Stony Brook (SUNY), NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, and the National Oceanic and Atmospheric Administration (NOAA). The study is an interagency cooperative effort involving NSF, NASA, and NOAA; support for

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some researchers is being provided by the Chemical Manufacturers Association.

Wyoming scientists are launching thirty 19,000-cubic-foot balloons instrumented to measure ozone and three 54,000-cubic-foot balloons carrying aerosol measuring devices. The SUNY team is using microwave devices to measure chlorine monoxide profiles in the atmosphere, while the JPL group is measuring absorption by atmospheric gases of solar infrared radiation. NOAA scientists are using an ultraviolet spectrophotometer to determine nitrogen dioxide and ozone levels.

These 12 scientists are among the approximately 350 researchers who are participating in the 1986-1987 research program of the USA Antarctic Program. Highlights of this austral summer's program appear in this article; descriptions of each of the 74 projects to be conducted in Antarctica between August 1986 and April 1987 begin on page 4. Support and logistics for this austral summer are described in an article beginning on page 18.

Atmospheric physics

How did matter in the universe form into galaxies and clusters of galaxies? Astronomers from the University of Delaware and AT&T Bell Laboratories in Holmdel, New Jersey, will focus on this fundamental question while working at the geographic South Pole during November and December 1986. They will try to detect fluctuations in the microwave background radiation that permeates the universe. So far, measurements of this radiation have shown that it is remarkably uniform in all directions, but theorists suggest that microwave radiation must contain fluctuations, called anisotropy, that describe the initial clumping of matter during the formation of structure in the universe.



Editor: Winifred Reuning

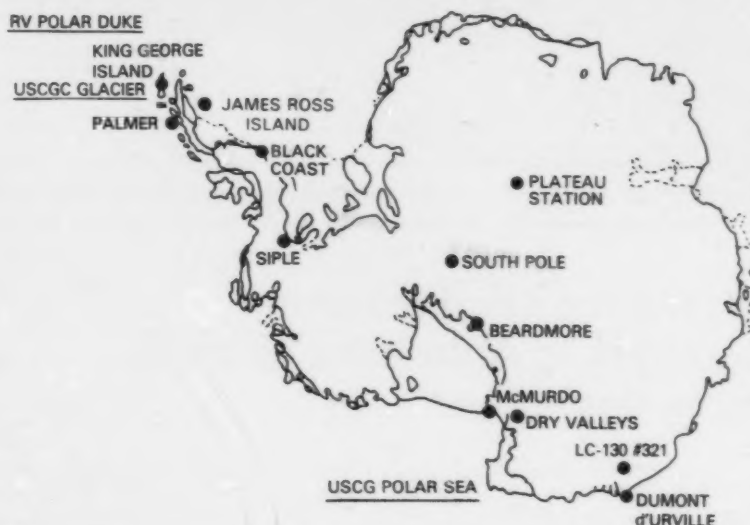
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The Director of the National Science Foundation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this agency. Use of funds for printing this periodical has been approved by the director of the Office of Management and Budget through 31 March 1991.

U.S.A. ANTARCTIC PROGRAM 1986-1987

LOCATIONS OF MAJOR ACTIVITIES



In 1965 two AT&T Bell Laboratories scientists, who received the Nobel Prize for their discovery, found that background radiation permeates all regions of the sky. This discovery solidly supported the theory that the universe began with a tremendous explosion of an extremely dense, hot and compact object. During this explosion (the "Big Bang"), events occurred that dictated the present nature of the universe. Microwave background radiation is a remnant of the early universe and has cooled by expansion to a temperature of 2.75°C above absolute zero from about 1,000 billion billion billion degrees at the earliest epoch imagined by physicists.

This austral summer the astronomers will use a 1-meter radio telescope, which was designed by the Bell Laboratories researchers. The telescope can receive signals with wavelengths of about 3 millimeters, which is well below the limit predicted by theorists as necessary to record fluctuations in background radiation. To attain the required sensitivity, liquid helium cools the telescope's receiver to 0.3°C above absolute zero (-273.15°C). Because the telescope will be at the earth's axis, it will remain fixed and the earth's rotation will provide the scanning. Infrared observations made 2 years ago confirmed that the South Pole has the lowest water vapor content and "sky noise" on Earth. If this experiment is successful the South Pole could become a center for this type of cosmological research.

Glaciology

Working at Amundsen-Scott South Pole Station, University of Kansas scientists will test the capabilities of a newly designed sled-drawn radar system to measure ice thickness and document the internal layering of the ice sheet. Glaciologists have used radar for probing glaciers and ice sheets and for extensive surveys in Antarctica since the 1950's. For several of these surveys, more data are needed to answer such questions as whether the ice sheet is expanding or contracting and to trace the flow of ice in West Antarctica.

The new system, designed by the Kansas scientists, uses a radar technique that achieves high signal-to-noise ratios with relatively low-power, solid-state transmitters. This system can be used from a sled or from a Twin Otter, a small two-engine airplane often flown to support research in Antarctica. A second version will be designed for use on ski-equipped Hercules (LC-130) airplanes.

In other glaciology projects, Ohio State University investigators will continue collecting and analyzing data from ice cores to learn more about climatic variations over the past 2,000 years. This austral summer drillers will retrieve four ice cores from two sites in East Antarctica for the Ohio State researchers. Previous studies at one of the sites suggest that a 450-foot core should provide approximately a 2,600-year record. Shallow-depth ice cores that





document climate variations since the Holocene—the last 10,000 years of Earth's history—are essential for interpreting longer records and may provide data for predicting future climates.

Biology

Three teams of scientists will investigate what makes the coastal shelf ecosystem of the Antarctic Peninsula biologically richer than surrounding waters. This region is the principal breeding, feeding, and spawning ground for krill (*Euphausia superba*), the crustacean that has become the focus of antarctic marine ecosystem research in the last few years. While the structure of this ecosystem has been widely studied, little is known about how it functions. Working aboard the 219-foot, ice-strengthened research ship *Polar Duke*, two groups of scientists from Scripps Institution of Oceanography and a team from the University of Hawaii will take part in this project called "Research on Antarctic Coastal Ecosystem Rates and Processes" (RACER).

Another group of biologists from Scripps Institution of Oceanography will study the energy expended by emperor penguins as they breed and forage near Cape Washington in northern Victoria Land. Penguins comprise 75 to 85 percent of the birds in southern ocean ecosystems. Although most southern penguins depend on krill for food, emperor and king penguins do not. These two species differ in size, breeding habits, and distribution but share similar life styles. Specifically, they depend on fish and squid for food, can dive deeper than other penguins—to depths as great as 600 feet—and remain near their breeding areas year-round.

Last austral summer the researchers and co-workers completed an investigation of the king penguin. Using a newly designed submersible microprocessor, they will record for the first time the swimming velocity and diving capabilities of the emperor penguin. They also will measure the average metabolic rate for birds at the colony. With these data and those obtained in the king penguin study, the researchers will develop better models for the impact penguins have on the southern oceans, calculate how efficiently growing chicks convert food into energy, and better understand how these species exploit their environment.

Ocean sciences

The 3-million-square-mile Weddell Sea, one of the Earth's largest sea-ice environments, will be studied by a Woods Hole Oceanographic Institution scientist. The objective of this project is to obtain data on the flow, origin, and seasonality of organic and inorganic particles in the open sea. Although recent research has helped clarify the distribution of carbon and other organic matter and sedimentation processes in antarctic continental shelf waters, such

processes in open areas of the southern oceans are not well understood. Each summer the retreat of the ice edge generates a set of unique circumstances, which scientists believe may control sedimentation. One important question the scientists hope to answer is whether or not particulate organic material produced in the open sea remains suspended or is dissolved under the ice during the austral winter.

This project, the Weddell Sea sediment trap experiment, is one of 10 projects to be conducted by U.S. scientists in cooperation with the West German antarctic program during two winter cruises of the West German icebreaking research ship *Polarstern*. Twenty-one U.S. scientists are participating in the two cruises.

Marine geologists from Rice University will continue their investigation, which began in 1979, of the sediments that blanket the antarctic sea floor and of the relationship between different glacial and ocean conditions. Although they will continue work near the Antarctic Peninsula, they will also work in the McMurdo Sound region, which includes various glacial marine environments in a relatively small and accessible shelf basin. They are also interested in the origin of marine canyons on the western side of the Sound and the role that the canyons have in sediment transport to the ocean floor. Working from the U.S. Coast Guard ice-strengthened ship *Glacier* during February 1987, they will conduct seismic profiling to examine the glacial history of the region and compare glacial records, which include the last 600,000 years, from McMurdo Sound and the adjacent Ross Sea shelf.

Earth sciences

Geophysicists from New Mexico Institute of Mining and Technology will study the nature, behavior, and evolution of the magma chamber of Mount Erebus, the 3,794-meter volcano on Ross Island. The volcano, which has been active for at least 1 million years, contains the world's only easily accessible convecting lava lake. This lake—the top of the volcano's magma chamber—is a window through which the processes operating in the chamber system can be studied.

In September 1984, the volcano was convulsed by a series of large eruptions, believed to be the largest since Mount Erebus was discovered in 1841. Based on observations made in December 1984, scientists believe that the volcano has entered a new eruptive cycle. Observations made last year indicate that a lava lake 45 feet in diameter exists in a site similar to that of the former lake. To document changes in Mount Erebus' activity, scientists will collect samples of materials ejected from the volcano. Older lava flows and rock material broken into fragments by volcanic or igneous action will be mapped and exam-



NSF photo by Ann Hawthorne.

Since the International Geophysical Year (1957-1958), the United States has continuously supported research in Antarctica. From stations like Amundsen-Scott South Pole Station (pictured above), scientists collect data that provide insight into not only the nature of Antarctica but also such global concerns as the history of climatic change, formation of the continents, and the nature of Earth's upper atmosphere.

ined. From the ejected materials, the researchers will determine the temperature of the lava lake, measure the emission rate of sulfur dioxide and particulate matter, and examine changes in the composition and crystallization of magma.

In eastern Ellsworth Land, U.S. geologists will work with the British Antarctic Survey to study the Antarctic Peninsula-eastern Ellsworth Land plate, the largest and most exposed part of the Earth's crust in any area of Antarctica. It also has the greatest potential for containing economic metallic mineral deposits. The geology of this area will be compared with that of nearby previously studied regions. To aid in mapping, the British Antarctic Survey will supply a Twin Otter airplane for 4 weeks.

The United States supports an active research program in Antarctica and the oceans that surround the continent. Approximately 1,500 Americans participate annually in this program, which draws upon the resources and scientists of numerous U.S. universities, federal agencies, and several commercial firms. In addition to conducting research, U.S. citizens operate ships, aircraft, stations, and camps.

In response to a Presidential directive, the National Science Foundation (NSF) funds and manages the USA Antarctic Program, which provides "an active and in-

fluent presences in Antarctica designed to support the range of U.S. antarctic interests." NSF supports research in glaciology, earth sciences, ocean sciences, marine and terrestrial biology, medical sciences, and atmospheric sciences, as well as develops goals for antarctic science and plans logistics requirements. Logistics and support in Antarctica is provided by the U.S. Naval Support Force Antarctica (NSFA), the Antarctic Development Squadron Six (VXE-6), the U.S. Coast Guard, and an NSF contractor ITT/Antarctic Services, Inc. (ITT/ANS).

Planned research projects, 1986-1987

Biology

Marine, freshwater, and terrestrial life in Antarctica present vivid contrasts. In the oceans surrounding the continent, life is abundant. In scattered ice-free areas on the continent some organisms have adapted to the extreme cold and dryness, but the diversity of these organisms is low. Unique environmental factors—particularly large, dynamic sea-ice zones, near-constant sea temperatures close to the continent, and arid cold and nutrient-poor terrestrial areas—have combined with the continent's isolation to generate special adaptations and interactions between species. Biologists have identified and quantified much of Antarctica's marine and terrestrial life; today they probe the behavior, evolution, and adaptations of these biota, the interactions of flora and fauna with the environment, the relationships among organisms, and man's impact on these ecosystems. With these data they can better understand the biology of the region, develop comparative models of more complex ecosystems in lower latitudes, and provide information needed to manage and conserve antarctic living resources.

Winter oxygen levels in lakes. George M. Simmons, Virginia Polytechnic Institute and State University, and Robert A. Wharton, Jr. and Christopher P. McKay, National Aeronautics and Space Administration. Antarctic lakes are enriched perennially with high levels of oxygen. Although in other environments these levels would be lethal to many organisms, in antarctic lakes biota flourish. Biotic activity, large shifts in the freeze-thaw cycle of the ice cover, and the entry of glacial meltwater apparently influence the oxygen budget in these lakes. Scientific understanding is incomplete because researchers have not measured oxygen levels during the austral winter. At Lake Hoare in Taylor Valley, we will acquire winter data via re-

mote sensing and construct a model for the oxygen cycle. Data collected during the 1985-1986 austral summer indicate that this lake is undergoing an unanticipated dynamic change. The ice cover is now only 10 feet thick instead of the previously measured 15 to 18 feet, the sediment layer appears to be farther down in the ice-cover, and the supersaturated oxygen zone is now about 2 to 3 feet lower in the water column. We will retrieve and reset sediment traps placed last year and sample water from meltstreams, a moat, the lake, and lake ice for analyses of seasonal changes in oxygen and nitrogen. Taking into account the lake's reduced ice cover, we will continue evaluating seasonal fluctuations of chlorophyll *a* and oxygen concentrations. Data will be collected with temperature and oxygen electrodes. We also will sample algal mats in experimental growth plots established during the 1980-1981, 1981-1982, and 1985-1986 austral summers and set up new ones. A reconnaissance trip to Lake Joyce is planned to collect data for comparison with the Lake Hoare data. When these data are combined with other data on antarctic lake ecology, we will better understand how growth and production in microbial communities are related to changes in the oxygen budget and how shifts in the freeze-thaw cycle affect oxygen levels. (S-002)

Behavior and ecology of Weddell seals. Donald B. Siniff, University of Minnesota. We will continue studying Weddell seals at a site near Hutton Cliffs, Ross Island. Our project focuses on male territorial and reproductive behavior, age-specific survival of pups born in these colonies, and the activities of and interactions between mothers and pups. By using physical and electronic markers over the last two austral summers, we have identified the peak of breeding activity underwater and have obtained the first proof of the degree of polygyny in this species. As males appear at the site, we tag them with proximity transmitters and small radio transmitters to record their activity in and out of the water. Females also are equipped with proximity recorders to document approaches and copulatory activity by males. Before the pups are born, we weigh the females; after birth mothers and pups are weighed weekly throughout the lactation period to find out how much time the mothers invest in caring for the pups. Early in October 1986 we will set up a remote camp near Hutton Cliffs to continue implanting radio transmitters. In November and December we will census a seal population at the ice edge near Cape Royds, Ross Island. With these observations we will document the number of immature seals and improve our estimates of survival rates for younger age classes. (S-004)

The role of glycopeptide antifreezes in freezing avoidance by fishes. Arthur L. DeVries, University of Illinois. Living organisms adjust protein synthesis rates in

response to environmental factors as a fundamental strategy for survival. We have discovered that most antarctic fish living in ice-laden shallow water possess either glycopeptide or peptide compounds that have antifreeze properties. Results of our experiments indicate that eight glycopeptides lower the freezing point of body fluids below the temperature of the seawater (-1.9°C). This season we will catch various species of native antarctic fish to continue our investigation of their antifreeze systems. Live fish, caught during the season under the sea ice near McMurdo Station, from cracks near the ice edge, and in shallow water near Cape Royds and the Dailey Islands, will be studied at the McMurdo Station aquarium to determine the distribution and role of glycopeptides in various body fluids and tissues. We also will study what part glycopeptides have in freezing avoidance in intestinal fluid, what mechanisms cause them to move from blood to bile, and why they are not digested as they move through the intestinal track. We will continue biochemical studies of the noncolligative lowering of the freezing point of water by examining the interaction between antifreezes and ice. Additionally, we will examine the role of epithelial tissues in preventing ice propagation into undercooled fluids by determining at what subfreezing temperatures these tissues act as a barrier, with or without the presence of glycoproteins. (S-005)

Energetics of adult and larval krill (*Euphausia superba*). Langdon Quetin and Robin Ross, University of California, Santa Barbara. *Euphausia superba* (krill) and related euphausiid species are the most abundant animals in the southern ocean. Besides being exploited heavily by almost all antarctic marine carnivores, krill is the focus of a small fishery. Our objective is to assess the impact of food availability on the energetics of reproduction in adults and on the survival, development, and growth of larval stages of krill. Four factors affect how much food is available for reproduction—how much is ingested, how efficiently it is assimilated, what the metabolic costs are for swimming and maintenance, and how energy is partitioned for growth and reproduction. Working aboard the *Polar Duke* in two regions west of the Antarctic Peninsula, we will search for and collect live krill for laboratory experiments three or four times, November 1986 through January 1987. During these cruises we will measure assimilation efficiency and rates of ingestion, instantaneous growth, and egg production. At Palmer Station we will complete our winter experiments on how different conditions affect larval growth and development and will continue investigating oxygen consumption and ammonia excretion at different swimming speeds for adult krill. To do this we will drive krill to swim at different constant speeds in an annular respirometer. We will also test two assumptions that are critical

to the method that we use to measure field ingestion and assimilation efficiency. The results of this project should contribute substantially to understanding aspects of krill biology that are either unknown or poorly understood. (S-014)

Cryptoendolithic ecosystems. E. Imre Friedmann, *Florida State University*. The climate of much of Antarctica, especially in ice-free regions, is arid; katabatic winds descending from the polar plateau heighten desert conditions. Because environmental extremes in such regions limit life to a narrow zone under the surface of certain rocks, certain microorganisms inhabit cracks and the structural cavities of porous rocks. We will continue sampling communities at Linnaeus Terrace in the Asgaard Range and other sites in the ice-free valleys of southern Victoria Land, including Battleship Promontory, Mt. Lister, Mt. Fleming, and University Valley. Our research includes micrometeorological measurements, estimation of respiration and net photosynthetic rates for microbial communities, calculation of total yearly productivity, taxonomy of cryptoendolithic lichens and algae, and the study of non-photosynthetic bacteria. We also will investigate the interactions between the organisms and the rocks they inhabit (including chemistry, leaching, and biological weathering), how the rocks are colonized, and the yearly accretion of nitrogen in rocks. This research will provide a more comprehensive understanding of cryptoendolithic microbial ecosystems, including their implications for earth sciences. (S-015)

Emperor and king penguin brooding and foraging energetics. Gerald L. Kooyman, *Scripps Institution of Oceanography*. Penguins comprise 75 to 85 percent of the birds in the southern ocean ecosystem. Although most southern penguins greatly depend on krill as a food source, emperor and king penguins do not. These two species differ in size, breeding habits, and distribution, but they have similar life styles. Both species depend entirely on fish and squid for food, can dive deeper than other penguins (to depths as great as 200 meters), and remain near their breeding areas year-round. Few investigators have studied the free-ranging energetics of penguins, even though penguins are major predators in the southern ocean food web. During the 1985-1986 austral summer we completed our investigation of the king penguin. This austral summer we will work at an emperor penguin rookery near Cape Washington in northern Victoria Land. Using a newly designed submersible microprocessor, we will record for the first time swimming velocity, time/depth profiles, and dive patterns of the emperor penguin. These data will help us to understand how these penguins respond physiologically to diving. To measure energetics we will use water labeled with the

isotopes oxygen-18 and tritium to determine water turnover rates and carbon-dioxide production. While conducting these studies we will measure the average metabolic rate of the birds at the colony. With these data and data obtained previously on the king penguin, we will develop better models of the impact that penguins have on the southern ocean ecosystem, calculate how efficiently energy is transferred from the environment to growing chicks, and understand better how these species exploit their environment. (S-026)

Microbial and vertebrate chitin degradation. James T. Staley, *University of Washington*. Chitin is a primary component of the exoskeletons of marine invertebrates. In the southern oceans high primary production causes correspondingly high concentrations of herbivorous consumers—particularly krill whose dry weight is about 8 percent chitin. Over time the antarctic marine environment would lose an enormous quantity of nitrogen and carbon if chitin were not degraded and remineralized. Although few animals and microorganisms possess enzymes that solubilize chitin, our laboratory investigations

indicate that fin whales and Adélie penguins produce a pancreatic chitinase, an externally secreted digestive enzyme that degrades chitin. To determine the importance of chitin in the carbon and nitrogen cycles of antarctic coastal waters, we will study animals that feed primarily on krill and determine if chitin is being degraded during passage through the digestive tract. Tissue samples and gastrointestinal contents from a limited number of Adélie penguins and crabeater seals will be collected and tested for the presence of chitinase. Working near Palmer Station, we will survey the water column and sediments from small boats and *Polar Duke*. We also will investigate the microbiology and degradation of chitin in soils in penguin rookeries. During a *Polar Duke* cruise along the Antarctic Peninsula (in collaboration with investigators from the University of Hawaii), we will collect water-column and sediment samples and material from sediment traps. We will sample areas near Palmer Station where there are large populations of crabeater seals. The chitinase from the animals mentioned above, from bacteria residing in the water column, and from sediments will be isolated, purified, and characterized. (S-032)



NSF photo by Ann Hawthorne.

Biologists collect fish through a hole in McMurdo Sound sea ice. They are studying these fish to determine how natural antifreeze compounds help fish to avoid freezing in ice-laden antarctic waters.

Pinniped studies. John L. Bengtson, *National Marine Mammal Laboratory*. Working aboard the U.S. Coast Guard ice-strengthened ship *Glacier*, we will study seals in the region of James Ross and Seymour islands. We will census fur, crabeater, and leopard seals, test and deploy electronic tracking and recording devices, and determine feeding habits and reproductive status. Surveys will be conducted from the ground and from *Glacier's* helicopters. (S-034)

Thyroid hormone kinetics in cold-exposed man. John T. O'Brian, *Department of Internal Medicine, Naval Hospital Bethesda*. In mammals many factors regulate the basal metabolic rate to satisfy energy and heat requirements. Thyroid hormones are important for maintaining basal metabolism and, along with other endocrine factors, are related to nonshivering thermogenesis. However, adaptation to the environment can alter the serum concentrations of these hormones. Before and during the 1980-1981 austral winter, thyroid hormone homeostasis was studied in individuals with normal thyroid activity. Although in this investigation the serum levels of two thyroid hormones—thyroxine (T_4) and a form of triiodothyronine (rT_3)—remained unchanged and the level of free triiodothyronine decreased, the response of the thyroid stimulating hormone (TSH) to the thyrotropin releasing hormone (TRH) increased by 50 percent over 42 weeks. We believe this change in hormone activity is related directly to multiple cold exposures. Because all known states of stress (except cold) blunt the stimulated TSH response, we believe that the increase in TSH response to TRH during cold adaptation suggests changes in the metabolism of the feedback control of hormones T_4 and T_3 . During the 1986-1987 austral summer, we will select six volunteers from the McMurdo Station wintering population to participate in our year-long experiment. To determine if production and clearance of thyroid hormones does increase, we will calculate the dynamics of thyroid hormone turnover during cold exposure by using radiolabeled T_3 and T_4 , administered intravenously to each of the six participants. The two hormones will be separated chromatographically from serial plasma samples and counted; from these data we will obtain turnover rates for the hormones. Our study will be conducted before cold exposure, after 24 weeks, and after 40 weeks in Antarctica. The results of this experiment will help to define a theoretical model for cold adaptation and clarify the contribution of thyroid hormones to this process. (S-035)

Energy metabolism in fish. Bruce D. Sidell, *University of Maine*. In the southern oceans only about 120 species (or less than 1 percent of all species worldwide) of fish have been identified; of these 65 percent belong to the suborder Notothenioidae. These fish, which evolved

isolated from other species, live in waters that have an average temperature of approximately -1.9°C near McMurdo Station and -1.1° to 0.3°C along the Antarctic Peninsula. As part of cold adaptation, most antarctic fish produce antifreeze compounds; however, biologists have found that Notothenioidae fish also accumulate substantial quantities of corporeal lipids. Although some biologists have suggested that lipids are a primary fuel for energy metabolism, this has not been demonstrated. Our goal is to use a cellular/biochemical approach to describe more completely energy metabolism in these fish. Specifically, we will evaluate critically enzymatic correlates of metabolic cold adaptation in tissues, assess the relative importance of carbohydrates and lipids as fuels for energy metabolism, determine the fatty acid composition of lipid stores, evaluate the suitability of predominant fatty acids as substrates for energy metabolism, and quantify geometric relationships of cellular ultrastructure that may be required for metabolic function at severely low body temperatures. To compare how diet and lifestyle affect energy metabolism, we will study benthic (*Notothenia gibberifrons*) and cryopelagic (*Trematomus newnesi*) fish. We will concentrate on major energy-consuming tissues (red and white skeletal muscle, cardiac muscle, etc.) in order to address questions of metabolic cold adaptation. The activities of key enzymes in pathways of energy metabolism will be measured at physiological temperature and compared with extant data from temperate fishes to determine if antarctic species are biochemically cold-adapted. Results of our study should help to determine whether metabolic rates of these fish are cold-adapted or whether fats are primary fuels for energy metabolism. These data also will contribute to a better understanding of the role of notothenioid fishes in the trophic structure of the antarctic marine ecosystem. (S-036)

Assembly and stability of microtubules in fish at low temperatures. H. William Detrich, III, *University of Mississippi Medical Center, School of Medicine*. Macromolecular assemblies of proteins perform many essential cellular processes. Cytoplasmic microtubules are tube-like, subcellular filaments composed of the major protein subunit, tubulin, and one or more microtubule-associated proteins (MAPs). The ordered assembly, maintenance, and disassembly of cytoplasmic microtubules play critical roles in cell division, nerve growth and regeneration, cell-shape determination, and cytoplasmic transport. At temperatures near 0°C the cold-labile microtubules of warm-blooded vertebrates break down rapidly into their simpler subunits. In contrast, the cold-stable microtubules of antarctic marine poikilotherms must be assembled and maintained at extremely low temperatures (approximately -2° to 2°C). Our goal is to deter-

mine the biochemical adaptations responsible for assembly, stability, and function of microtubule proteins in cold-adapted antarctic fishes (*Notothenia coriiceps neglecta*, *N. gibberifrons*, and *Chaenocephalus aceratus*) at low temperatures. Experiments during the last two austral summers demonstrated that cold stability of microtubules from these fishes is caused by alterations in the structures of tubulin subunits and, to a lesser extent, in the MAPs. At Palmer Station this summer, we will compare the structure and immunology of tubulins and MAPs from cold-stable and cold-labile microtubule systems. We will use one- and two-dimensional peptide mapping techniques to identify regions of structural variation between cold-stable tubulins from antarctic fish brains and cold-labile tubulins from bovine or catfish brains. Using monoclonal antibodies, we will assess the immunology of cold-stable and cold-labile tubulins. We also will compare MAPs from cold-adapted fishes, temperate fishes, and mammals and continue studying the thermodynamic forces that stabilize microtubules at low temperatures. (S-037)

Growth, photosynthesis, and carbon metabolism of phytoplankton in the southern ocean: diel periodicity in cell metabolism. Richard B. Rivkin, *Horn Point Environmental Laboratory, University of Maryland*. In a changing environment, phytoplankton typically adapt by altering a metabolic pathway or pattern of nutrient use. Over a short time these adaptive mechanisms enable the cell to resume efficient operation. In the southern oceans and under annual ice, phytoplankton are exposed to discontinuous light and nutrients because of turbulent motion, seasonal variations in light, varying cloud cover and wave action, and localized and periodic regeneration of nutrients. Biologists in 1980 reported that southern ocean phytoplankton can incorporate 70 to 80 percent of recent products of photosynthesis into lipids and smaller amounts into proteins. This finding contrasts with the traditional interpretations of primary production measurements. Studies in the Arctic, the Antarctic, and laboratories suggest that the pattern of carbon uptake varies significantly with species and geographic location. Our objective is to examine how fluctuating light cycles are related to carbon metabolism, photosynthesis, and growth of individual species and phytoplankton assemblages. From late August until mid-November, we will collect samples and measure growth rates and temporal changes beneath the ice and in open water of McMurdo Sound. We also will measure the photosynthesis-light relationship, enzyme activity, cell division, the photoheterotrophic metabolism of dissolved organic compounds, and partitioning of recent photosynthesis products into low molecular weight compounds, lipids, polysaccharides, and proteins. We will estimate the species contribution to total and net plankton pri-

mary production and the time required to adapt to new light and temperature regimes. By examining specific species in nature and in laboratory cultures, we will determine the relationship between cellular biochemistry and the division rate of individual algal species and evaluate the coupling between carbon metabolism and phytoplankton growth. (S-038)

Physiology of sea-ice algae: Changes in photosynthetic metabolism during the course of a spring bloom. Anna C. Palmisano, Ames Research Center/National Aeronautics and Space Administration, and Cornelius W. Sullivan, University of Southern California. Microalgae remain trapped in the bottom of the annual sea ice in McMurdo Sound during the entire spring bloom. These standing crops have as much as 300 milligrams of chlorophyll *a* per square meter. Ice microalgae also may serve as a model for studying physiological changes during an algal bloom. Because vertical mixing and horizontal advection are absent and losses from grazing and sinking are reduced, we are able to follow a single community through bloom development and decay. Our objectives are to examine physiological changes in ice algae from the beginning of the bloom in November through its decay in January in both bottom congelation and platelet ice communities and to determine the primary factors affecting eventual senescence. We will focus on changes in photosynthetic metabolism occurring at the start, peak, and decline of the ice algal bloom and use growth rates to estimate changes in biomass over several days. The factors that may contribute to biological changes in ice algal communities before ice ablation include osmotic stress, nutrient limitation, self-shading, and oxygen inhibition. We will test the effects of these variables on natural populations and laboratory cultures. (S-039)

Pygoscelid penguin population studies in Admiralty Bay. Wayne Z. Trivelpiece, Point Reyes Bird Observatory. Penguins are major predators of krill (*Euphausia superba*) and an important component of the antarctic marine food web. To thoroughly understand the structure and function of the antarctic ecosystem, biologists must have information on population dynamics, as well as the factors that regulate the size of penguin populations, especially pygoscelid penguins, the dominant antarctic genus. The three pygoscelid penguins—Adélie (*Pygoscelis adeliae*), chinstrap (*P. antarctica*), and gentoo (*P. papua*)—nest sympatrically at Point Thomas, King George Island, near the Polish Arctowski Station. Here the gentoo population is stable while the Adélie and chinstrap populations are increasing. For several years we have banded penguins at this site and studied their breeding and feeding ecology. Our objective is to collect data on these banded penguins to determine the relationships of sex, age, and

experience to fecundity and survival. From October 1986 until February 1987, we will make daily observations of banded, known-age Adélie, chinstrap, and gentoo penguins in two rookeries on King George Island. Data from this project contribute to scientific understanding of the structure and function of the antarctic marine ecosystem and add to present knowledge of population dynamics of marine birds. (S-040)

Trace metal transport processes in Lake Vanda and the Onyx River. William J. Green, University of Hawaii. Lake Vanda, the largest volume closed lake in southern Victoria Land's ice-free valleys, provides an excellent ecosystem for investigating metal dynamics and phase specific removal mechanisms. Besides being fed by a single river, the Onyx, the lake has a reasonably well-characterized chemistry and biology, a permanent ice cover that largely excludes airborne entry of metals, and a setting that is remote from human influences. During this austral summer we will study the solid phase speciation of chromium, magnesium, iron, cobalt, nickel, copper, zinc, cadmium, lead, and aluminum. We will determine what phases control the transport of each metal in Lake Vanda and the Onyx River, trace phase-specific metal associations from river to lake to sediments, obtain metal residence times and relative residence times over 2 years, compare trends in metal reactivity in the Vanda-Onyx system to trends in the oceans, examine possible relationships between the phase associations of incoming metals and their lake residence times, model metal-sulfide equilibria in the stable anoxic brine of Lake Vanda to better understand possible resolubilization and mobilization of certain metals under high-sulfide concentrations, and examine metal profiles in sediment pore waters to determine the role of diagenetic remobilization in the lake's trace metal budget. To accomplish these objectives we will install 10 traps in Lake Vanda to collect particles settling through the water column. We also will measure sulfur species in the Vanda anoxic zone, collect 100 samples for trace metal analysis, and take sediment cores for information on pore water chemistry. By combining these data with data obtained during a 1980 study, we will expand our understanding of the processes regulating metal transport and concentrations. (S-041)

Trophic positions of benthic rhizopoda. William L. Stockton, University of California, San Diego. Although benthic foraminifera are abundant in many marine communities, their trophic positions and significance in energy transfer and community dynamics remain unknown. Much of the published information on benthic foraminifera is limited to zoogeographic and systematic studies of about 60 of the 4,000 cataloged species. Our research focuses on one type of benthic foraminifera, rhizopods, which may be important in energy transfer in benthic food webs. Capa-

ble of rapid growth on various foods, rhizopods may represent a large benthic biomass that preys on microbes and is food for higher trophic levels, especially small species and developmental stages of larger ones. McMurdo Sound has diverse habitats with distinctive foraminiferal assemblages, ranging from shallow-water to deep-ocean species. Because the polar environment has pronounced seasonal fluctuations in benthic populations, we can sort out ecological relationships more easily. We will analyze the energy flow into rhizopod populations, evaluate the standing stocks, biomasses, and chemical and caloric compositions of rhizopods, and determine what species are most likely to prey on them. We will work mostly at New Harbor, where we will dive under the ice to collect samples. Observations also will be made on the eastern and western sides of McMurdo Sound. (S-043)

Coastal ecosystem rates and processes: photobiology and primary production. Osmund Holm-Hansen, Scripps Institution of Oceanography. Compared to offshore waters, the coastal shelf region along the Antarctic Peninsula is rich in primary production; consequently, there are larger populations of higher trophic levels, particularly of krill (*Euphausia superba* Dana). Our project is part of a multi-disciplinary study, "Research on Antarctic Coastal Ecosystem Rates and Processes" (RACER), that is directed to increase understanding of the paths and rates of energy flow within this important ecosystem. We will focus on the hypothesis that physical mixing in coastal waters favors increased water-column stability and greater residence time of phytoplankton in shallow mixed layers and allows higher rates of photosynthesis. Because evidence supports the hypothesis that antarctic phytoplankton are light-limited, we will study phytoplankton and biomass distribution, rate processes, and photoadaptation in relation to available light to determine conditions for maximum energy input to this ecosystem. Working aboard the *Polar Duke*, we will survey coastal shelf and deep ocean waters repeatedly to determine temporal interactions between physical dynamics and plankton populations. Productivity will be determined by radiocarbon techniques; photoadaptation, by independent measurements of photosynthetic, optical, and biochemical parameters. (S-044)

Coastal ecosystem rates and processes: feeding, growth, and early development of krill (*Euphausia superba* Dana). Mark Huntley, Scripps Institution of Oceanography. As part of RACER (Research on Antarctic Coastal Ecosystem Rates and Processes) we will test four questions: Are the growth rates of larval krill a function of food availability, and, consequently, are these rates greater in productive waters of the coastal shelf ecosystem than in less productive, deep-water areas? Is the development of larval krill more rapid and

more direct in coastal shelf ecosystems than in deep water regions? Do juvenile and adult krill supplement their feeding by carnivorous feeding on other zooplankton, particularly when phytoplankton concentrations are too low to provide adequate food for metabolism? Do planktonic larval krill have a longer residence time in coastal waters than in offshore regions near the Antarctic Peninsula? We will observe surface and vertical distributions of krill and combine these data with data on biomass and distribution, larval physiology, and feeding and metabolism of juveniles and adults. Answers to the questions that we have posed are fundamental to understanding *Euphausia superba* and the ecosystem. (S-045)

Coastal ecosystem rates and processes: microbiology and vertical flux component.

David M. Karl, *Hawaii Institute of Geophysics, University of Hawaii at Manoa*. Despite low temperatures, extended darkness, deep vertical mixing of surface waters, and other environmental factors, the southern oceans support moderate but patchy biotic activity. Our knowledge of the carbon pathway and energy flow through the lower trophic levels of the oceanic food web is incomplete. In particular, the role of microheterotrophs in antarctic marine food webs and the immediate fate of phytoplankton production needs to be clarified. As part of the multidisciplinary project RACER (Research on Antarctic Coastal Ecosystem Rates and Processes), our objective is to evaluate several ecological predictions, based on a central hypothesis that relates physical stability of the water column to biotic productivity at all trophic levels. We will attempt to define the mechanisms, pathways, and rates of coupling between photoautotrophic and microheterotrophic populations, to measure steady-state concentrations and turnover rates of selected components of the dissolved organic carbon pool, and to estimate the downward vertical flux of particulate organic materials, including microorganisms. Working aboard the research ship *Polar Duke*, we will measure biomass and metabolic activity of microbial populations, relationships between primary and secondary production, downward flux of carbon, nitrogen, and phosphorus with sediment traps, and dissolved nutrients, gases, and macromolecules in water samples. Data obtained from these experiments will add to our understanding of the rates of primary and secondary production and may be useful in formulating a general model of carbon and energy flow in antarctic marine ecosystems. (S-046)

Physiological ecology and energetics of Adélie penguins. Mark A. Chappell, *University of California, Riverside*. Adélie penguins (*Pygoscelis adeliae*) are the most abundant penguins in the Antarctic and are important components of its marine ecosystem. Although investigators have studied Adélie breeding ecology and be-

havior, many aspects of thermoregulation in this species have not been described, and the importance of thermal factors in breeding is not understood. Our objective is to describe temperature relations and energetics during incubation and nestling growth by focusing on two aspects of thermoregulation. Working in rookeries near Palmer Station, we will measure continually the microclimate and observe penguin behavior to establish a range of thermal conditions in adult birds and chicks. In the laboratory we will study physiology, including carbon-dioxide consumption, water loss, and ventilation rate. These data, along with field measurements and observations, will provide insights into the significance of heat and cold stress, the energetic costs of maintaining normal body temperature, daily energy expenditures, and the role of thermal and climatic factors in penguin breeding and thermoregulation. (S-047)

Earth sciences

During the last three decades geologists have surveyed, mapped, and described geologic features in Antarctica. These investigations have enabled them not only to understand regional geology and geophysics but also to address topics that apply to other areas of the world. These data have supported such theories as plate tectonics and the existence of the former supercontinent Gondwana and have contributed to the solution of more fundamental problems such as mountain-forming processes and marginal basin evolution. With most of the necessary reconnaissance work completed, geologists and geophysicists now focus on determining the role of the south polar region in global geodynamics, understanding the evolutionary history of the endemic biota of the continent and surrounding seas, and understanding Antarctica's role in the evolution of present ocean circulation. Geologists also are evaluating mineral and hydrocarbon resource potentials of the continent and the continental shelf.

Ultra long-period seismic and gravity observations. Leon Knopoff and W.D. Smythe, *University of California, Los Angeles*. Because Amundsen-Scott South Pole Station is a seismically quiet platform, which lies on the Earth's rotational axis, we use this site to measure long-period oscillations of the Earth with two ultra long-period seismometers (modified LaCoste-Romberg gravity meters). The location of this station on the Great Circle Paths that coincide with portions of the Mid-Atlantic Ridge and the East Pacific Rise is advantageous for studying phase velocities sensitive to the middle-mantle structure under an oceanic ridge. We also hope to observe motions of the Earth's inner core. The station's location, its symmetric position between the oceans, and

the low noise at the site favor observations of long-period tides and free oscillations. Our goal is to attain a better understanding of the deep structure and lateral inhomogeneities of the Earth. (S-050)

Geodetic satellite observations. James R. Clynch, *Applied Research Laboratories, University of Texas at Austin*. At McMurdo Station we will operate and maintain a geodetic satellite observatory to collect dual-frequency doppler data from polar-orbiting satellites. These satellites transmit similar data to South Pole Station on specific orbits; data from both stations help determine the spatial and time variations of the ionosphere and provide geodetic positioning controls. Data from the South Pole will be relayed via the United States via the University of Texas INMARSAT geosynchronous satellite communications system. (S-051)

Geodesy and seismology. Lowell Starr, *U.S. Geological Survey*. At Amundsen-Scott South Pole Station two USGS technicians will operate electronic Doppler equipment to track overflights of Navy navigational satellites throughout the year. These data will be used in studies of polar motion and ice movement. The South Pole seismometer is operated as part of the Worldwide Standardized Seismology Network. The technicians will also operate the station's science computer. (S-052A)

Topographic surveys. John Kelmelis, *U.S. Geological Survey*. Two U.S. Geological Survey cartographers and two New Zealand field engineers will connect prior surveys to create a single geodetic network in the ice-free valleys of southern Victoria Land and the Ross Island area. This network will support 1:50,000-scale mapping by the U.S. and New Zealand antarctic programs. These controls will be used later to support the Shuttle Imaging Radar project. U.S. cartographers also will locate the true geographic South Pole and will check the control network near Amundsen-Scott South Pole Station. (S-52B)

Meteoritics. William A. Cassidy, *University of Pittsburgh*. Meteorites are useful in investigating possible changes through time in the meteoroid flux at Earth, measuring the cosmic-ray flux in past eras, searching events in which asteroid parent bodies were disrupted, and defining the abundances and characteristics of pre-solar-system organic molecules. This austral summer we will survey from the site of the 1985-1986 Beardmore Glacier field camp and continue to the Lewis Cliff Ice Tongue, about 30 miles south of the field camp site. We will systematically search for meteorites, map finds, collect ice samples (for isotopic oxygen-18/oxygen-16 analyses and age determinations), and explore potential meteorite-stranding surfaces along the Walcott Neve. If we have enough time, we will search for meteorites in the Do-

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NSF photo by Ann Hawthorne.

A geologist waits by his equipment as a U.S. Navy UH-1N helicopter lands. The United States began using these helicopters to support research in Antarctica in the early 1970's. Besides supporting research near McMurdo Station, the UH-1Ns also are used at large field camps in remote areas of Antarctica.

minion Range. One member of our party will go also to Amundsen-Scott South Pole Station to check cosmic dust collectors. (S-058)

The James Ross Island Basin and the evolution of the Antarctic Peninsula.

David H. Elliot, *Ohio State University*. The James Ross Island Basin contains the only exposed sequence of Upper Cretaceous to Lower Tertiary marine strata in Antarctica. One island of the James Ross group, Seymour Island, has strata of Campanian to Paleocene age and late Eocene to early Oligocene age. These poorly consolidated sedimentary rocks contain plant microfossils, diverse invertebrate fauna that is generally well-preserved, and vertebrate faunas including the first fossil marsupial from Antarctica. The Campanian to Paleocene sequence spans the Cretaceous/Tertiary boundary, which we have tentatively located at the top of the Lopez de Bertodano Formation. Since 1975 we have spent four austral summers in this region. Our objectives are to determine the provenance and depositional settings of the sedimentary rocks through time and to relate these to the evolution of the antarctic cordillera. We will map deposits, measure geologic sections, and collect samples. The ages of rocks in the basin range from late Jurassic to early Oligocene. This age range enables us to investigate the tectonic evolution, paleo-current data, the provenance of detrital sediments, and the petrology of volcanic material. The results of our field studies

and laboratory work will be combined with information on the magmatic history of the cordillera and will help establish a model for tectonic evolution of the northern Antarctic Peninsula. This history of development will contribute to a general understanding of paleobiogeography and paleoceanography in the Southern Hemisphere as well as an understanding of the development of the James Ross Island Basin. (S-060)

Tectonic development of West Antarctica and its relation to East Antarctica.

Ian W.D. Dalziel, *Institute for Geophysics, University of Texas at Austin*. Over several years we have compiled data and conducted field research to gain an understanding of the relationship between East and West Antarctica through geologic time. Our investigations have focused on the Scotia Arc and the region at the base of the Antarctic Peninsula extending to the Ellsworth, Thiel, and Whitmore Mountains. During the 1983-1984 austral summer, U.S. and British geologists began an intensive investigation in the Ellsworth Mountains and Martin Hills, at Mt. Smart, and near Siple Station. Field work includes geology, paleomagnetism, geochronology, and geophysics, with radio-echo sounding and aeromagnetic surveys conducted by British geophysicists. This summer we will work with British Antarctic Survey personnel who will conduct an airborne geophysical investigation in the Ellsworth Mountains region. This investigation will attempt to define the limits of the blocks

and determine the tectonic nature of the ice-covered area between them. (S-063A)

Kinematic evolution of the Scotia Ridge:

a study of orogenic processes at convergent plate margins. Ian W.D. Dalziel, *Institute for Geophysics, University of Texas at Austin*. Because the structural history and geometry of the rocks forming the West Antarctic-Andean Cordillera in the Scotia Arc are now fairly well defined, we are interested in understanding the process that formed the Scotia Arc. Our objective is to study the kinematic evolution of the subduction complex along the Pacific margin of the Antarctic Peninsula in the South Shetland Islands. By studying the structure and metamorphics of the region, we hope to better understand the movement and processes that placed this complex in its present continental margin setting. We also will study Tierra del Fuego and South Georgia Island on the northern Scotia Ridge to understand the evolution of the southernmost Andean Cordillera. Studies over the last 15 years have shown that orogenic uplift in this area was initiated when an Early Cretaceous back-arc extensional basin closed in the mid-Cretaceous. From the research ship *Polar Duke*, we will conduct a multi-channel seismic survey to determine the deep structure of the cordillera. A detailed study of the structural and metamorphic geology in a critical zone along the continental side of the former back-arc basin will provide valuable information on the kinematic development of the orogen. (S-063B)

Cenozoic micropaleontology and biostratigraphy of the Victoria Land Basin.

Peter-Noel Webb, *Institute of Polar Studies, Ohio State University*. Sites in the McMurdo Sound region (Victoria Land Basin), the valley basins in the Transantarctic Mountains, and the inland slopes and crests of these mountains provide data crucial to unraveling Cenozoic geology. Over the last 5 years the greatest progress has been made in deciphering the late Paleogene (about 30 million years ago) and Neogene records, although much is still unknown about the early and middle Paleogene. This austral summer we will work with the New Zealand Antarctic Research Program and provide on-site biostratigraphic control when they drill a stratigraphic hole near Butter Point. Later in the summer we will collect rock samples along the McMurdo Ice Shelf. Geologists have suggested that the fossiliferous Late Cenozoic terrestrial Sirius Formation, which crops out along the crest of the Transantarctic Mountains, may have originated in the marine "Wilkes-Pensacola Basins" inland from the Transantarctic Mountains. We believe that some of the Sirius Formation marine sediments that contain fossils may have come from a geologic setting similar to the McMurdo Ice Shelf. Consequently, by collecting samples in this region, we hope to be able to determine if the ice shelf contains marine material with ages similar to the Paleogene,

Neogene, and Pleistocene sediments of the Sirius Formation. Although the present McMurdo Ice Shelf is only about 6,000 years old, it may be useful for understanding multiple marine and glacio-marine phases of the Sirius Formation. Our long-term objectives are to develop a Cenozoic biostratigraphy based on microfossil groups and apply paleoecological data to solving problems of basin evolution, mountain building, and climate fluctuation. (S-064)

Dry valley real-time telemetry seismology. Nicholas A. Orsini and L. G. Holcomb, U. S. Geological Survey Albuquerque Seismological Laboratory. The availability of high quality seismic data from Antarctica is a long-term objective of many investigators. Such data, when combined with data from the Worldwide Standardized Seismological Network, would provide needed azimuthal control for locating seismic events in the Northern and Southern Hemispheres. During the 1983-1984 austral summer we surveyed sites in southern Victoria Land's ice-free valleys. In the upcoming austral summer we will install and calibrate propane tanks at Mt. Newall and at a borehole site in the ice-free valleys of southern Victoria Land and install a borehole seismometer at the borehole site for long-term monitoring of seismic events. After our equipment is installed, we will activate recorders to relay data. Eventually, data will be transmitted in real time via a synchronous satellite to the U. S. Geological Survey Albuquerque Seismological Laboratory as part of a larger seismic data collection network. (S-078)

Regional geology of the southern Antarctic Peninsula. Peter D. Rowley, U.S. Geological Survey, Reston, Virginia. The Antarctic Peninsula and eastern Ellsworth Land belong to a Mesozoic-Cenozoic magmatic arc complex that appears to be superimposed on one of at least four small lithospheric plates of continental crust in West Antarctica. This plate, the Antarctic Peninsula-eastern Ellsworth Land plate, is the largest and best exposed plate and has the greatest potential of any area in Antarctica for containing economic metallic mineral deposits. We are particularly interested in the central Black Coast, the axis of the southern Antarctic Peninsula, and in some coastal areas of the southern Antarctic Peninsula near the southern end of the plate. The objectives of our investigation, which will be conducted in cooperation with the British Antarctic Survey, are to map, describe, and interpret the geology of these three areas. None of these areas have been explored; they are south of the areas studied by British geologists and north of areas study by American geologists. Also they comprise the largest area in West Antarctica of totally unknown rocks. Because we will be working in an unexplored region, various topical studies will be developed in the field. These may include petrology and geochemistry of plutonic and volcanic rocks, structural geol-

ogy, paleomagnetism, mineral deposits, paleontology, stratigraphy, stratigraphic correlation, and isotope geology. The geology of the area will be compared with that of the nearby previously studied southern Black Coast, Lassiter Coast, Orville Coast, English Coast, and eastern Ellsworth Land. To aid in mapping, the British Antarctic Survey will supply a Twin Otter airplane for 4 weeks. (S-080)

Volcanology of Mount Erebus. Philip R. Kyle, New Mexico Institute of Mining and Technology. Mount Erebus contains a persistent convecting phonolite lava lake. This lake, which represents the top of the volcano's magma chamber, can be viewed as a window through which the processes operating within the magma chamber system can be observed. In September 1984 a series of large magmatic eruptions rocked the volcano. These were probably the largest eruptions since James Ross discovered the volcano in 1841. Based on observations made in December 1984, we believe that the volcano has begun a new cycle of strombolian eruptions. Observations made in December 1985 indicate that a lava lake, 15 meters in diameter, is present in a site similar to that of the former lake. To better understand the nature, behavior, and evolution of the Mt. Erebus magma chamber, we will continue observing the volcano this austral summer and document the nature and changes in volcanic activity. We will collect samples of material ejected from the volcano for later analysis. A detailed petrologic/geochemical/isotopic study of these samples, as well as samples from older lavas flows, will be done to evaluate the petrogenesis of the magma. We will map older lava flows and pyroclastic deposits to examine the geologic history and evolution of the volcano and will examine the petrologic evolution of the phonolite magma in the lake to compare it to the older lava flows. We also will determine the temperature of the lava lake, measure the emission rate of sulfur dioxide and particulate matter, and examine changes in the composition and crystallization of the anorthoclase phonolite magma by analyzing recently ejected material. (S-081)

Origin and depositional setting of pre-Devonian, coarse-clastic sequences in the central Transantarctic Mountains: evidence of one or more tectonic events. Margaret N. Rees, University of Nevada, Las Vegas. The Transantarctic Mountains extend over 4,000 kilometers between the Weddell and Ross seas and form the western boundary of the east antarctic craton. Within the mountain chain and in the Ellsworth Mountains in West Antarctica, Upper Proterozoic and Lower Paleozoic rocks crop out in isolated areas. From regional mapping and some detailed studies geologists have shown that generally these areas have similar geologic histories, but these studies also have indicated that differences in stratigraphy and structure exist. Our study focuses on

two sequences of conglomerate and sandstone, one in the central Transantarctic Mountains and the other in northern Victoria Land. The similarity in stratigraphy of the clastic sequences in these areas suggests that a genetic relationship may exist between the two geographically widespread areas. To improve our understanding of the tectonic and geologic history of rocks in these areas we will analyze facies to establish the depositional settings, evaluate the sediment composition to ascertain the lithologies and ages of the source areas, determine ages of interbedded volcanic rocks, collect fossils from fine-grained sedimentary units to establish the age of deposition, and examine the relationship between the coarse-clastic sequences and underlying formations. From these data we will try to determine if the tectonic setting that controlled the origin and distribution of the sequences later deformed them. If we can determine that there is a genetic relationship between the coarse-clastic rocks of the Bowers terrane and those in the central Transantarctic Mountains, these data will greatly modify scientific understanding of the lower Paleozoic development of the western continental margin of Antarctica and perhaps of Gondwana. (S-082)

Exploration for fossil land mammals on Seymour Island. Michael O. Woodburne, University of California, Riverside. In March 1982 the discovery of mammal fossils (*Antarctodolops dailyi*) on Seymour Island confirmed theories that predicted that past presence of land mammals, particularly marsupials, in Antarctica. The recovered fossils were related to an extinct South American marsupial family *Polydolopidae* known there in rocks about 35 to 60 million years old. We estimate that the antarctic fossils are approximately 40 million years old and believe this indicates that marsupials dispersed from South America to Antarctica by at least this time. This discovery, as well as other fossil discoveries during the 1984 austral summer, have emphasized the importance of this region to understanding the paleontology, biogeography, and biochronology of the Southern Hemisphere. This austral summer we will continue to search for more fossil mammal remains in rock formations on Seymour Island and for additional cetacean, bird, and plant fossils. Our investigation also will improve our understanding of geologic relationships and stratigraphic controls of that portion of the sequence that contains the Cretaceous/Tertiary boundary. (S-084)

Paleontologic investigation of the Cretaceous/Tertiary boundary on Seymour Island. William J. Zinsmeister, Purdue University. A detailed geologic investigation of the James Ross Island region will enhance understanding of the evolution and faunal content of the late Mesozoic-early Tertiary James Ross Island basin. It also will help define the evolutionary relation-

ship between this area and the Antarctic Cordillera, the tectonic setting of the Peninsula region, the evolution of southern hemisphere shallow-water biota, and the changing patterns of land and sea connections. Our objective is to complete a geologic and paleontologic survey of the uppermost Cretaceous and lower Tertiary sequence on Seymour Island. We will document stratigraphic relationships of the Cretaceous-Tertiary boundary and the occurrences of invertebrate and vertebrate fossils. In other areas of the world an iridium anomaly has been reported at the Cretaceous-Tertiary boundary. To determine if this anomaly occurs in the Antarctic Peninsula region, we will collect samples for geochemical analysis; samples from above and below the boundary also will be collected for radiometric dating. (S-086)

Geochemical studies of Paleozoic granitic rocks of the central Transantarctic Mountains. Donald J. DePaolo, *University of California, Los Angeles*. In the central Transantarctic Mountains between the Nimrod and Beardmore glaciers, an exposed segment of bedrock appears to straddle the boundary between old Precambrian craton and late Precambrian geosynclinal sediments. Also, in this region the Paleozoic batholith clearly overlaps the edge of Precambrian basement. During the 1985-1986 austral summer we completed reconnaissance mapping and sampling of granites in the central Transantarctic Mountains between Nimrod and Ramsey glaciers. This austral summer we will map and sample granites and metamorphics in the Miller Range and granitic rocks in the Gabbro Hills region, south of the mouth of the Shackleton Glacier. By working in the Miller Range, we will be able to investigate in detail the structural geology and metamorphic petrology of Precambrian metamorphic rocks and complete sampling of Paleozoic granites. In the Gabbro Hills, we will extend our sampling to an area that geologists believe was the furthest edge of the continental margin during the late Precambrian and early Paleozoic. Our objectives are to understand the petrogenesis of the granitic rocks, to investigate the age and origin of the Precambrian basement rocks, and to develop tectonic-magmatic models of early Paleozoic evolution of the continental margin. Because igneous rocks intrude into both geosynclinal metasedimentary rocks and Precambrian crystalline basement in this region, we will be able to use neodymium, strontium, oxygen, and uranium-lead isotopic systematics to assess what role crustal assimilation had in the origin of the granitic magmas. Using neodymium and strontium isotopic systems, we will determine the age and vertical structure of the Precambrian basement rocks about which little is known. Our analytical work includes electron microprobe analysis, analysis for major and trace elements, and isotopic analysis. The results of this study will help

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explain the petrologic evolution of the Transantarctic Mountains. (S-094)

Cretaceous and Tertiary palynology of the James Ross Island basin and western Ross Sea. Rosemary A. Askin, *Colorado School of Mines*. Our objective is to establish a biostratigraphic zonation for the marine and nonmarine palynomorph succession of Seymour, Snow Hill, and James Ross islands. Samples collected on Seymour Island during three expeditions have yielded rich palynomorph assemblages, including many new species. Some of these have been found in sediment cores from the Ross Sea, but others are apparently peculiar to the James Ross Island basin. We will collect additional samples and correlate our age and environmental interpretations with other paleontologic and sedimentologic studies. From the resulting Cretaceous-early Tertiary palynostratigraphic reference sequence, we will be able to better define ages elsewhere in Antarctica. We also hope to determine the depositional environment, nature of the original plant communities, and major environmental changes in the James Ross Island basin. (S-097)

Glaciology and glacial geology

Antarctica's ice sheet covers 97.6 percent of the continent in thicknesses up to 4.8 kilometers. Its history, derived from ice cores, the terrestrial geologic record, and the marine sedimentary record, reveals the history of climatic change and environmental conditions in Antarctica. By studying the continent's glacial history, scientists also learn about the impact of humans on the atmosphere, the timing of northern and southern hemisphere glaciations, global ocean circulation, and the dynamic response of ice to changes in the atmosphere and ocean boundary changes. From deep ice cores taken from the east antarctic ice sheet, glaciologists have acquired a 150,000-year record; continued study of deep ice cores from the antarctic ice sheet could provide a climatic record for more than 500,000 years. Data from ice-free areas of Antarctica have enabled glacial geologists to develop models on ice-sheet fluctuations and soil development. Over the last 30 years, such technological advances as radar-echo sounding and Doppler-satellite positioning have provided new data on ice thickness, internal layering in the ice sheet, and the velocity of ice movement. With this information and with data from ice cores, glaciologists are determining ice sheet stability, understanding the role of ice in climate, and assessing the potential impact of the antarctic ice sheet on sea level.

Ice core drilling. Karl C. Kuivinen, *University of Nebraska*. Ice cores provide valuable information on past atmospheric con-

stituents and climate. We will drill at two sites in East Antarctica—one near the old U.S. station Plateau (82°S 43°E) and one to the west of an ice divide within the Ross Ice Shelf catchment basin (approximately 82°S 86°E)—to support investigators from Ohio State University (S-171). At each site we will collect a 150-meter core and a 50-meter core. In addition, three members of our group will go to Byrd Surface Camp in West Antarctica to begin relogging the 2,164-meter core hole drilled in 1968. While at Byrd, we will do reconnaissance, extend the casing in the core hole, and drill an access hole. (S-150)

Development of a radar system for ice probing. Richard K. Moore, *University of Kansas*. Radars for probing the ice sheets in Antarctica and Greenland have been used for extensive surveys since the 1950's. Although several surveys have been done in Antarctica, the need exists to expand these to obtain data not only for general studies but also for detailed investigations aimed at answering questions related to mass balance and flow of ice from the west antarctic ice sheet. A number of radar systems have been operated in Antarctica, but these are becoming outdated and need to be replaced. We have designed a system that uses coherent radar techniques to achieve a high signal-to-noise ratio with relatively low-power, solid-state transmitters. The system will be capable of taking measurements from a sled or from a Twin Otter airplane; a second version will be designed for use on a ski-equipped Hercules (LC-130) airplane. Working at South Pole Station this austral summer, we will test the measuring capabilities of a sled-drawn 150 megahertz radar with a probing accuracy of 5 meters at 50-meter intervals. This will enable us to see how well the radar works in the field. (S-152)

Late Cenozoic glacial history and soil development. George H. Denton, *University of Maine*. The history of antarctic ice dynamics relates to the causes of global ice ages and provides insights into the behavior of past northern hemisphere ice sheets. During the Quaternary, changes in sea level and precipitation controlled ice-sheet fluctuations, as ground ice repeatedly covered peripheral continental shelves. By combining geologic and soil studies, we have developed a model for late Cenozoic ice-sheet fluctuations and soil development. The model has enabled us to infer multiple, earlier glaciations with ice-volume maximums greater than those during the Quaternary. This austral summer our field work will concentrate the ice-free valleys of southern Victoria Land. Working near the Rhone Platform and Taylor Glacier, we will collect volcanic rocks for radiometric dating to determine when the east antarctic ice sheet overrode the Transantarctic Mountains. In the eastern Wright Valley, we will complete mapping of moraines and glacial drift to tie together

the valley floor moraines with basal till deposited when the east antarctic ice entered this area. We will also complete mapping of moraines and drifts in Arena Valley in the Quartermain Range. Data obtained from this site when combined with data from the Beardmore Glacier region, the Ellsworth Mountains, and northern Victoria Land will help us to reconstruct the east antarctic ice sheet during the time that it overrode the Transantarctic Mountains. We also will complete mapping of moraines and drift sheets in Beacon Valley and near Mt. Feather. (S-156)

Late Cenozoic glacial history and soil development. James G. Bockheim, *University of Wisconsin, Madison*. The history of antarctic ice dynamics relates to the causes of global ice ages and provides insights into the behavior of past northern hemisphere ice sheets. During the Quaternary, eustatic sea level and precipitation controlled ice-sheet fluctuations, as grounded ice repeatedly covered peripheral continental shelves. By combining geologic and soil studies we have developed a model for late Cenozoic ice-sheet fluctuations and soil development. The model has enabled us to infer multiple, earlier glaciations with ice-volume maximums greater than those during the Quaternary. Salts from marine aerosols are predominate in soil formed during this time. To extend our antarctic data, we will work with investigators from the University of Maine (S-156) in the ice-free valleys of southern Victoria Land. In Taylor and Wright valleys and nearby mountain areas, we will

use soils in relative-age dating of glacial deposits and study the nature, distribution, and origin of salts in the soil. These data, combined with other data from southern Victoria Land and the Beardmore Glacier area, will not only help to test our model but also contribute to an understanding of antarctic soil formation over the last several million years. (S-161)

Glaciological and climatological analysis of the past 2,000 years from ice cores.

Ellen Mosley-Thompson and Lonnie G. Thompson, *Ohio State University*. Recent analysis of intermediate-depth (500 meters or more) ice cores, which record Late Wisconsin and Holocene climate, demonstrate that large-scale climate fluctuations, such as glacial and interglacial periods, occur at approximately the same time worldwide. Paleoclimatic investigations indicate that records in ice cores, tree rings, and lake sediments can be used to resolve short-term climate variations. Because of paleoclimatic reconstructions based on these short-term records, scientists believe that climatic events once thought to be regional are local manifestations of global climate fluctuations. Our objective is to ascertain the spatial and temporal coherence of climatic variations (inferred from ice cores) across Antarctica. Data that describe antarctic paleoclimatic history will be incorporated with data from other latitudes to produce a global synthesis of climatic variations over the last 1,000 to 2,000 years. To obtain data, drillers will retrieve four ice cores, two 100-meter cores and two 50-meter cores, from two sites in East Ant-

arctica. Previous studies near the former U.S. station Plateau suggest that a 150-meter core from this area should include approximately a 2,600-year record. Although accumulation rates have not been estimated for the second site, which is west of an ice divide lying within the Ross Ice Shelf catchment basin, we believe that a 150-meter core should record about the same or slightly shorter number of years than the Plateau Station core. Such shallow-depth ice cores that document climate variations since the Holocene are essential for interpreting longer records and, as some scientists believe, may provide important data for predicting future climates. Near each coring site, we will excavate two snow pits, take three shallow cores (two 15-meter and one 6-meter), record densities and visual stratigraphy in each snow pit, and collect additional samples for analysis. In our laboratory we will analyze samples for concentration and size distribution of insoluble particulates and use ion chromatography to study specific ion species. The concentration and chemical nature of these particulates provide information about the types of atmospheric particulates deposited during the time recorded in the ice cores. (S-171)

Geological and geochemical study of Elephant Moraine, Allan Hills.

Gunter Faure, *Ohio State University*. Elephant Moraine, which is located about 70 kilometers west of Reckling Peak and 80 kilometers north of the Allan Hills on the east antarctic ice sheet, consists of a thin layer of rock fragments. We believe that this moraine began to form about 30,000 years ago when the east antarctic ice sheet had thinned significantly in this area. Also our data suggest that Elephant Moraine is forming at a site where a series of ridges that are part of the western flank of the Transantarctic Mountains is emerging from beneath the ice sheet. These rocks, along with rocks from a nearby basin that opens to the north, resemble cirques that may have formed during the beginning of glaciation in Antarctica when today's outlet glaciers were valley glaciers that drained the ice that accumulated at higher elevations in the Transantarctic Mountains. This austral summer we will map Reckling Moraine and do geophysical studies near Reckling and Elephant moraines. We also will remeasure ablation stakes set up in 1985. (S-189)

An ice sheet, which at its thickest is almost 3 miles deep, covers 97.6 percent of Antarctica. Data from ice cores taken from the ice sheets in East and West Antarctica help to describe past climates, changes in the atmosphere and world sea level, human impact on the atmosphere, and terrestrial, volcanic, and cosmic fallout.

NSF photo by Ann Hawthorne



Ocean sciences

The southern ocean is important for understanding the history of the world's oceans, changing oceanic conditions, and climatic and glacial history. During the last 30 years, circumpolar and regional surveys have significantly advanced scientific understanding of sea-floor spreading as the Earth's primary geophysical process, the complex nature of the circum-

antarctic current, the formation of Antarctic Bottom Water (a cold, dense water mass that sinks and spreads globally), and climatic cycles and variations as recorded in ocean bottom sediments. The use of data obtained by polar-orbiting satellites is improving understanding of such oceanic features as the changing sea-ice cover and surface temporal variability of the Antarctic Circumpolar Current. In the future satellite observations and real-time transmission of data from unmanned systems will augment existing data on the nature of southern oceans, particularly during the austral winter. Such data on the air-ice-ocean interactions during the austral summer and winter is crucial to discern Antarctica's role in global climate change.

Marine geology of the Antarctic Peninsula continental margin. John B. Anderson, *Rice University*. Since 1979 we have collected and described sediments that blanket the antarctic sea floor; we have related sedimentary facies to glacial and oceanic conditions. This austral summer we will investigate gravity-driven sediment transport in the McMurdo Sound region. We selected McMurdo Sound because it includes various glacial marine settings within a single, relatively small and accessible shelf basin and because we are interested in the origin of submarine canyons on the western platform of the Sound and their role in sediment transport to the basin floor. During February 1987 from the U.S. Coast Guard ice-strengthened ship *Glacier*, we will conduct marine geologic and geophysical surveys in two areas—Sulzberger Bay and McMurdo Sound. We will take piston cores and conduct seismic profiling to examine the glacial history of the region and compare the Quaternary glacial record from McMurdo Sound with the adjacent Ross Sea shelf, as well as study sedimentation processes in this unique shelf setting. Sample locations and descriptions of materials collected will be made available to other investigators through the Antarctic Marine Geology Research Facility at Florida State University and through publication. (S-207)

Ross Sea heat flux experiment. R. Dale Pillsbury, *Oregon State University*, and Stanley S. Jacobs, *Lamont-Doherty Geological Observatory of Columbia University*. *In situ* melting of ice shelves by above-freezing sea water is a factor in ice-shelf mass balance, which, in turn, may relate to the mass balance of the west antarctic ice sheet and to sea level. Since 1983, we have focused on understanding ocean circulation on the antarctic continental shelf and the interactions of the ocean, sea ice, and glacial ice. Primarily, we are studying heat transport into the sub-ice shelf cavity via a relatively warm current "jet" that crosses the continental shelf at intermediate depths. Ice-shelf melting and winter formation of sea ice strongly influence shelf-water thermohaline and geochemical characteristics and, consequently, con-

tribute significantly to the formation of Antarctic Bottom Water. During January and February 1987, investigators from Oregon State University and Lamont-Doherty Geological Observatory will work aboard the U.S. Coast Guard icebreaker *Polar Sea*. Oregon State investigators will recover one current-temperature-conductivity meter (CTD) deployed during the 1984-1985 austral summer and will do data reduction. Lamont-Doherty investigators will measure and interpret temperature, salinity, and density fields by collecting and processing CTD and expendable bathythermograph (XBT) data. XBTs will be released along the Ross Ice Shelf and at hydrographic stations at about 168°E and at 172°30'W where an array of current meters was moored in early 1985; these current meters will be retrieved this year. By recovering and extending the time period of these data sets that are near an inflow of warm water to the sub-ice shelf cavity, we hope to learn more about the variability of Ross Sea circulation and about the interactions of ocean and glacial ice. (S-211)

Sinking and suspended particulate matter on the continental shelf. Robert B. Dunbar, *Rice University*. Modern antarctic shelf sediments have sources and transport paths that are unique to the present glacial setting. Studies during three previous austral summers along the antarctic continental margin have shown that biotic and physical processes affect sediment transport and deposition. Through surface sediment experiments that estimate the sinking flux of particulate matter and reveal different depositional styles at various points we will characterize sedimentary processes on the antarctic continental shelf. For example, in the Bransfield Strait biogenic phases of rapid transit to the sea floor are diluted within the mid- and deep-water column by materials eroding from the continent, while, in the Ross Sea, the amount of material from the continent is low and biogenic-aggregate residence times in the water column are high. This austral summer we will extend our investigation of sediment processes in the southwestern Ross Sea. Between October and December 1986 we will sample particulate matter with sediment traps at 11 sites below the sea ice in McMurdo Sound—near Barnes Glacier, Erebus Glacier Tongue, Cape Chocolate, New Harbor (2 sites), Granite Harbor (3 sites), Tripp Bay, Cape Crozier, and the southern Erebus Basin. We also will test an acoustic release device, which will be used during future austral summers, if possible, and deploy a single lightweight wire-and-rope sediment-trap mooring from the edge of the Ross Ice Shelf near Cape Crozier. In January and February 1987 we will retrieve the sediment trap mooring, collect surface sediments, and conduct a high-frequency seismic survey of several regions in McMurdo Sound from the U.S. Coast Guard ice-strengthened ship *Glacier*. This phase of

the project will be conducted in conjunction with other marine geologists from Rice University (S-207). Our investigation is part of an integrated study to measure primary production in surface waters, particle fluxes at depth, and sediment accumulation rates on the sea floor. The results will provide data for paleo-oceanographic studies and for investigations of geochemical cycles of nutrient elements in the southern oceans. We will also characterize the input of aeolian debris to McMurdo Sound, the flux of which to antarctic shelf sediments is presently unknown. (S-216)

Chronometry and geochemistry of antarctic siliceous sediments. David J. Demaster, *North Carolina State University*. In marine environments silica (SiO_2) is an important nutrient used by such organisms as diatoms, radiolaria, siliceous sponges, and silicoflagellates for growth and formation of skeletal material. The best estimate of the dissolved silica supply to the oceans is 4.6×10^{14} grams per year. Based on reported biogenic silica accumulation rates, only 70 percent of the silica supplied to the oceans can be accounted for in marine siliceous deposits. On the antarctic continental shelf biogenic silica accumulation accounts for 1.4×10^{14} grams, a significant portion of the "missing silica." During 2 years of antarctic research we have documented an accumulation of 0.4×10^{14} grams of biogenic silica per year in Ross Sea sediments. If these accumulation rates in the Ross Sea are typical for the rest of the antarctic continental shelf, the total amount of biogenic silica in this repository may be as high as 1.3×10^{14} grams each year. Extending our earlier research, we will collect sediment cores while working aboard the *Polar Duke* from the antarctic continent shelf on the west coast of the Antarctic Peninsula. Sediment accumulation rates in these deposits will be determined by using lead-210. For three cores taken from beneath Polar Front, we will use radium-226/thorium-230, protactinium-231, and thorium-230 to establish rates of sediment accumulation. We are also interested in the rapidly accumulating siliceous sediments located beneath the Polar Front because 36 percent of the dissolved silica that reaches the oceans accumulates in these deposits. (S-220)

Winter Weddell Sea project 1986: physical oceanography. Arnold L. Gordon, *Lamont-Doherty Geological Observatory, Columbia University*. The southern oceans are major components in the ocean-atmosphere system. The region is the dominant area for deep-water formation and ocean ventilation and is an important climate modulator because of the insulating effect and high albedo of the extensive seasonal sea-ice cover. The sea ice is coupled to the ocean-atmosphere system; its temporal and spatial distribution is determined by the nature of atmospheric forc-

ing and the ocean's density structure. Measurements made during the ice-free austral summer suggest the winter ocean-atmosphere coupling significantly affects global heat, water, and gas budgets. Data on winter conditions in the southern oceans are limited to inferences from summer observations, data acquired during the 1981 U.S.-U.S.S.R. investigation of the northern third of sea ice, Weddell Sea, observations from a few coastal stations, and data obtained in 1912 during the *Deutschland* cruise. Between June and November 1986 U.S. and West German scientists aboard the West German icebreaker *Polarstern* will investigate the Weddell Gyre in the Weddell Sea. During two 80-day cruises we will take measurements by lowering conductivity-temperature-depth (CTD) and current meter profiles from the ship and its helicopters, either through openings in the sea ice or in polynyas. Our objective is to better understand the ocean-ice-atmosphere coupling in this region, water mass conversion, and deep ocean ventilation. Working with investigators from West Germany and Great Britain, we will obtain a data set that will add significantly to sea-ice, ocean circulation, and global climate modeling. It will provide ground-truth for satellite data and essential information on surface, deep, and bottom water formation, sea-air heat flux, and uptake of carbon-dioxide and other substances by the ocean. (S-221)

Winter Weddell Sea project 1986: collection and modeling of upper ocean temperature/salinity data from ice-locked drifters. Douglas Martinson, *Lamont-Doherty Geological Observatory, Columbia University*. As participants in the U.S.-West German investigation of the Weddell Gyre, during the 1986 austral winter we will collect temperature/conductivity time series data from the upper regions of the ocean and refine our model of the ocean/sea ice coupling. To improve our understanding of the air-sea-ice coupling in the southern ocean, we will determine fluxes across the ocean-atmosphere boundary under different air, sea, ice, and lead conditions and study the dominant mechanisms and extent of water mass conversion that is brought about by forcing when the ocean is ice covered. Our data and model, in addition to complementing other components of this program, will be a basis for future studies and will provide an observational foundation for future models. (S-219)

Winter Weddell Sea project 1986: chlorofluoromethanes. Ray F. Weiss, *Scripps Institution of Oceanography*. As part of the U.S.-West German multi-disciplinary project of the Weddell Gyre (see S-221), we will study winter distributions of anthropogenic chlorofluoromethanes CCl_3F (F-11) and CCl_2F_2 (F-12) and investigate winter surface water and atmospheric distributions of carbon dioxide, nitrous oxide, and

methane. Dissolved atmospheric F-11 and F-12 can be used as time-dependent tracers of ocean circulation and mixing processes on decadal time scale. From laboratory investigations which were conducted during the 1984 austral summer, we know that this type of measurement is well-suited for studies in the Weddell Gyre. Winter measurements should help significantly in studying the mechanisms and rates of Weddell Sea deep and bottom-water formation and in determining the role of winter air-sea exchange in ventilating water masses in this region. To measure carbon dioxide, nitrous oxide, and methane in the surface waters and atmosphere, we will use automated, high-precision gas chromatography along the entire cruise track. These data will help to determine the role of the Weddell Gyre as a winter source or sink of these environmentally important atmospheric trace gases. (S-222)

Winter Weddell Sea project 1986: nutrients. Louis I. Gordon, *Oregon State University*. During the winter cruise of the West German icebreaker *Polarstern* (see S-221), we will study dissolved oxygen, nutrients, and particulate silicon. We plan to extend, geographically and temporally, observations reported by A. Gordon in 1984 of dissolved oxygen depletion in Weddell surface water under the sea ice. By extending these observations, we will improve preliminary estimates of deep-water entrainment into ice-covered surface waters of the Weddell Sea. Oxygen and nutrient data will augment our understanding of the chemistry of the surface waters and will help us compare phytoplankton production in summer to calculated nutrient depletion in winter. We will measure the concentrations of particulate biogenic silica and mineral silica in shallow and deep water to help explain where silicic acid (relative to nitrate and phosphate) is concentrated. We will use our data to evaluate hypothetical water-type histories and trajectories that are necessary for interpreting time-dependent, geochemical tracer data sets obtained by other investigators during this cruise. (S-223)

Winter Weddell Sea project 1986: carbon dioxide. Taro Takshashi, *Lamont-Doherty Geological Observatory, Columbia University*. Based on recent measurements of the partial pressure of carbon dioxide in surface waters, we estimate that oceans in the Southern Hemisphere (south of about 30°S) take up carbon dioxide from the air at an annual rate equal to 25 percent of the annual industrial emission rate of carbon dioxide. Working with other U.S. and West German investigators aboard the *Polarstern* (see S-221), we will collect about 1,000 surface and subsurface water samples that will be analyzed for partial pressure of carbon dioxide and total carbon-dioxide concentration. A second 1,000 samples will be collected and stored for alkalinity determinations in our laboratory. Our

objective is to determine how summer conditions differ from winter conditions, when a large part of the southern oceans is ice-covered. From previous investigations we know that in the summer the southern oceans are a strong net sink for atmospheric carbon dioxide. But during the winter the sea-ice cover prevents the air-sea gas exchange. Additionally, beneath ice the mixing layers receive Weddell deep water by entrainment. At times the partial pressure of carbon dioxide in this layer apparently exceeds the partial pressure of carbon dioxide in the atmosphere. When the sea ice melts in the spring, this water is exposed and releases the carbon dioxide; consequently, the region becomes a net source of carbon dioxide. The partial pressure is lowered as photosynthesis uses the carbon dioxide in the air during the summer. Because geographic variability of carbon chemistry in this water layer is not known, we will investigate it and its relationship to oceanic features, as well as determining the carbon chemistry in this water and its influence on the overlying winter mixed layer. Additional measurements of chlorofluorocarbons will determine the transient increase in total carbon-dioxide concentration in the ocean water that results from increased amounts of atmospheric carbon dioxide from industrial emissions. Ultimately, our research will help to explain the nature of chemical and biological coupling and feedback of carbon dioxide in the atmosphere-ocean-climate system. (S-224)

Winter Weddell Sea project 1986: krypton-85. William M. Smethie, Jr., *Lamont-Doherty Geological Observatory*. Krypton-85, a radioactive inert gas with a half-life of 10.76 years, forms when uranium undergoes fission. Because nuclear testing and use of nuclear reactors have increased over the last 30 years, the concentration of krypton-85 has increased in the atmosphere. This gas enters the ocean by gas exchange and reaches an equilibrium in about 1 month. Krypton-85 is a powerful tool for tracing how surface ocean water enters the deep ocean because the approximate amount of time that it takes for the gas to be incorporated in surface waters is known. As part of the U.S.-West German investigation of the Weddell Sea (see S-221), we will measure krypton-85 to investigate mechanisms and rates of deep-water formation in the Weddell Gyre and the Weddell Sea, to determine the extent to which the winter surface-mixed layer is in equilibrium with atmospheric gases, and to establish the rate of gas exchange between the winter surface-mixed layer and the atmosphere. We also want to determine accurately the krypton-85 content of Antarctic Bottom Water because it is one of the major abyssal water masses in the Atlantic Ocean and mixes with other water masses far north of the equator. To interpret previously obtained samples collected in northern and tropical Atlantic



NSF photo by Ann Hawthorne.

An oceanographer lowers a CTD into the Ross Sea from the U.S. Coast Guard ice-breaker Polar Star. This instrument measures salinity, temperature, and depth and enables oceanographers to describe the structure of water masses.

Ocean waters, we need to know how much krypton-85 is contributed by the southern oceans. (S-225)

Weddell Sea sediment trap experiment.

Susma Honjo, Woods Hole Oceanographic Institution. Because of ice cover and lack of input from rivers, the sources, processes, and fate of organic matter in polar regions differ significantly from those in lower latitudes. Although recent research has helped to clarify biogenic carbon and other organic matter distribution and sedimentation processes in the antarctic continental shelf region, sedimentation processes in pelagic areas of the southern oceans are still not well understood. Our objective is to clarify the flux, origin, seasonality, and mode of vertical transport of biogenic and lithogenic particles in the pelagic Weddell Sea. The Weddell Sea is one of the largest sea-ice environments on Earth. As the ice-edge retreats each summer, a unique set of ecodynamics, which may control biogenic and lithogenic sedimentation in pelagic polar oceans, is generated. We are interested in describing the relation of particle flux to the seasonal succession of organic production and consumption that occurs throughout the year, especially in the open ocean. Another question is whether or not particles produced in the open ocean are suspended or dissolved under the ice during the austral winter. Continuing our 1985-1986 experiment, we will deploy time-series sediment traps, along with a time-series suspended particle/water collector, from the West Ger-

man research ship *Polarstern* at two depths where the annual ice coverage is about 70 percent. Data from our research will be applicable to the southern oceans and to other oceans frequently or permanently covered with ice. (S-226)

Winter Weddell Sea project 1986:

sea ice. Stephen F. Ackley, U.S. Army Cold Regions Research and Engineering Laboratory. Sea-ice cover in the southern oceans uniquely constrains the type of interactions that are possible between the ocean and the atmosphere. For example, ice-cover can alter greatly the albedo of the surface and the turbulent exchange from the ocean to the atmosphere. The region near the Weddell Gyre is a major dynamic area because sea ice undergoes a seasonal change of several million square kilometers. A large cyclonic subpolar gyre dominates the intense ocean currents in this area which is at the southern boundary of the westerly winds in the Southern Hemisphere, one of the more intense large-scale circulation features in the Earth's atmosphere. As part of the U.S.-West German investigation of the Weddell Sea (see S-221), we will participate in two cruises between July and November 1986. Our objective is to understand sea-ice-air processes to verify models and better use satellite remote-sensing to quantify these processes on hemispheric and seasonal scales. To meet these objectives, we will study mesoscale ice deformation, ice surface morphology and physical properties, and physical, chemical, and biotic properties of ice cores. (S-227)

Bransfield Strait hydrothermal activity.

Erwin Suess, Oregon State University. The Antarctic Peninsula formed as an "island arc" between the early Jurassic and Miocene when the Pacific plate was subducted beneath the antarctic plate. The South Shetland Islands, originally part of this arc, were separated from it when the Bransfield Strait opened, beginning about 1.4 million years ago. This separation, which is consistent with classical back-arc rifting, is still active. Our work with the scientists from West Germany's Alfred-Wegener Institute for Polar Research confirms this interpretation. The most convincing evidence that we have found is that there are submarine seeps of hydrothermal petroleum and slow advection of fluids through the sediment covering the axis of spreading. During the 1986-1987 austral summer, we will study the geochemistry, petrology, and oceanography of the Bransfield Strait to characterize early back-arc volcanism and to document and quantify hydrothermal interaction between volcanism and basin sediments. We will dredge dikes that penetrate basin sediments, core sediments across the axis of spreading, and survey the lower water column for temperature, radon, and anomalous silica and manganese contents. This study will help constrain mass flux estimates associated

with back-arc activity, yield new insight into thermal alteration mechanisms affecting marine organic matter, and may contribute to a better differentiation between back-arc basin basalts and mid-ocean ridge basalts and help in understanding the origin of ophiolites. This joint project between U.S. and West German ocean scientists will be conducted from the West German research ship *Polarstern*. (S-228)

Lower atmosphere studies

Antarctica affects and is affected by global climate. The coldest continent and the planet's largest heat sink, Antarctica appears to be important in long-term climate variability. Since the International Geophysical Year, scientists have studied the continent's climate and its various geographic regimes. From this research they have come to understand the major seasonal features of atmospheric circulation, the radiation and energy balances that affect climate and circulation, the nature of katabatic winds, and the transport of gases and aerosols. Today, research is directed toward such problems as the large-scale nature of the antarctic sink and its variations, coupled air-ice-sea interactions, how Antarctica affects global processes, and the response of Antarctica to climate change.

Winter meteorology in the McMurdo

Sound region. Austin Hogan, State University of New York, Albany. During the 30 years that Amundsen-Scott South Pole Station has operated, meteorologic and ozone observations have shown few instances of deep mixing or stratosphere-troposphere exchange. Ozone recordings obtained at the surface near McMurdo Station during late winter indicate that stratosphere-troposphere exchanges occur more frequently at this location than on the polar plateau. Our objective is to determine the atmospheric layers through which the various materials are transported to Antarctica and how these materials are transformed while enroute. This information is vital to climate modeling that includes aerosols as a component of the radiation budget and to an understanding of aerosol transport processes related to glacial and climatic history. During September and October 1986 we will examine aerosol and ozone exchange parameters near McMurdo Station. To do this we will measure sodium, sulfur, and soot components of aerosols and compare the time scale with the variation of meteorological events. These measurements and observations will enable us to estimate the exchange of marine and combustion-related aerosol components in Antarctica. (S-255)

Global monitoring for climatic change.

James T. Peterson, Environmental Research Laboratories, National Oceanic and Atmospheric Administration. Our team will

continue long-term measurements of trace atmospheric constituents that may influence climate. Two wintering personnel will measure carbon dioxide, surface ozone, winds, pressure, air and snow temperature, atmospheric moisture, and trace constituents from the station's clean air facility. The objectives are to determine the rate at which concentrations of these atmospheric constituents change and to examine sources, sinks, and budgets. Working with climate modelers and diagnosticians, we will use these data to determine how the rate of change in aerosol concentrations affects climate. In support of this project, personnel at Palmer Station will collect carbon dioxide samples for us. (S-257)

The windfield near Terra Nova Bay. David H. Bromwich, *Ohio State University*, and Thomas R. Parish, *University of Wyoming*. Katabatic (or gravity-driven) winds occur frequently along the steep coastal rim of Antarctica. The dynamics and behavior of these winds have been documented at various locations, but the actual forcing mechanisms and the relationship between coastal katabatic winds and interior conditions are not well understood. We know that the surface wind pattern over Antarctica is irregular and that cold air drainage patterns in the interior may influence the strength and persistence of katabatic winds. Where negatively buoyant air from a large interior catchment drains through a narrow section of the coastline, katabatic winds can be considerably strengthened. Field studies and theoretical evidence indicate that Terra Nova Bay is one of these regions. In this project, we will document the near-surface kinematic behavior of the katabatic flow using automatic weather stations and airborne surveys of sastrugi orientation. By using instrumented airplanes and satellite imagery, we will determine the physical characteristics of the boundary layer over the coast and near-interior sections of the region near the bay. Other objectives are isolating the dynamic and thermodynamic mechanisms responsible for anomalous longevity of katabatic flow away from the foot of the steep coastal slopes, evaluating the impact of synoptic scale disturbances on katabatic winds near the coast, numerically simulating the windfield over the Terra Nova Bay region and assessing the performance of this model. In November 1986, investigators from Ohio State University will measure the boundary layer structure from instrumented airplanes and photograph sastrugi orientation. In January 1987, investigators from the University of Wyoming will select sites for and oversee the deployment of automatic weather stations. (S-262 and S-263)

Automatic weather stations: operation and research. Charles R. Stearns, *University of Wisconsin*. Although information taken from satellites on antarctic weather

patterns is valuable, surface data are needed for confirmation. Automatic weather stations (AWS) measure surface pressure, air temperature, wind speed, and wind direction and transmit the data to satellites for interrogation by ground stations. We will use the weather stations to study the barrier wind along the Transantarctic Mountains, vertical motion and sensible and latent heat flux from the Ross Ice Shelf, foehn winds flowing from the Beardmore and Byrd glaciers onto the Ross Ice Shelf, katabatic flow at Reeves Glacier, and propagating weather systems at the South Pole. The weather stations will also provide meteorological support for aircraft operations at McMurdo Station. In the field we will check and service existing AWS units; new units will be installed on Reeves Glacier near Terra Nova Bay, on Scott Island (68°S 180°E), and on Balleny Island (66°55'S 163°20'E). These AWS units enable us to gather continuous and reliable meteorological data. (S-283)

The electrode layer at the South Pole. Robert F. Henry and Julie A. Samson, *State University of New York, Albany*. In fair weather, there is a region of positively charged space near the Earth's surface that results from the Earth's electric field. This field points downward; the positive ions drift downward, and negative ions upward. Because negative ions are repelled by the surface, this causes a near-surface excess of positively charged ions in the atmosphere. This phenomenon is known as the electrode effect. In the lower 10 meters of the atmosphere, or the electrode layer, the concentrations of ions are determined by the electric field strength and the strength of turbulent mixing. Numeric modelling of this effect is relatively simple, as is investigating it in air that is free of aerosols and surface-related ionization. The South Pole provides ideal conditions for an experimental study of this effect. We will measure sufficient parameters to characterize the electrode layer and will determine the turbulent fluxes of positive and negative ions. These fluxes will be compared with predictions of a simple model to which we will input the surface electric field and space-charge density. Specification of the surface electric field and space-charge density near the surface enables us to model the ionic eddy fluxes and the eddy diffusivity. By learning about the eddy diffusivity of the surface layer over Antarctica, we will better understand the turbulent fluxes of heat and water vapor to the ice sheet. (S-256)

National Ozone Expedition: Ultraviolet visible spectrophotometer measurements. Susan Solomon, *NOAA Aeronomy Laboratory*. Recent measurements show large, systematic changes of unprecedented portions in the ozone layer above Antarctica. Measurements taken at the British station Halley on the coast of East Antarctica show that the observed total ozone

abundance has decreased every austral spring since about 1975. The total amount of ozone is only about half that observed during the spring in the early 1970's and before. NASA satellite data confirm that the spring ozone depletion extends over most of Antarctica with maximum decreases inside the polar vortex. These dramatic deviations occur only from about mid-August to the end of October, with no observable changes during other seasons. Ozone, which plays a central role in the Earth's ecology, is the only atmospheric molecule capable of absorbing life-damaging ultraviolet photons in the wavelength range of 240 to 310 nanometers. Stratospheric models suggest that the ozone column over Antarctica should remain constant from July through October, but since 1975 this cycle has been changing. Current understanding of the mechanisms controlling the seasonal variation of ozone cannot explain these changes. In an effort to understand these changes, a series of special experiments will be conducted between August and November 1986 at McMurdo Station. Our portion of this suite of experiments focuses on the effects of chlorine on atmospheric ozone. We will use an ultraviolet spectrophotometer to measure vertical column abundances of nitrogen dioxide, nitrogen trioxide, chlorine dioxide, and stratospheric ozone. With these measurements we can detect how chlorine may affect the ozone layer. The nitrogen dioxide observations are particularly important because nitrogen dioxide plays an important role in two of the theories proposed to explain the ozone "hole." (S-286)

National Ozone Expedition: microwave radiometer measurements. Robert de Zafta and Philip Solomon, *State University of New York, Stonybrook*. To measure vertical profiles of chlorine monoxide, nitrous oxide, hydrogen cyanide, and ozone, we will use a millimeter-wave spectrometer. Of these measurements the levels of chlorine monoxide should help us to describe potential causes of the cause of the ozone "hole." If the ozone depletion is chlorine related, abundances of chlorine monoxide, taken approximately 12 miles above the Earth's surface, could be 100 times greater than normal. (S-287)

National Ozone Expedition: infrared spectrometer measurements. Crofton B. Farmer, *Jet Propulsion Laboratory*. We will use an infrared spectrometer to observe the sun and obtain a complete solar spectrum in the infrared range (from 2 to 16 microns). This will enable us to measure the number of chemicals in the air column—including hydrochloric acid, nitric acid, methane, chlorofluoromethane gases (F-11 and F-12), nitrous oxide, chlorine nitrate, and nitrogen dioxide. These measurements will enable us to determine the differences in chemical abundances outside of and within the ozone "hole." (S-288)

National Ozone Expedition: sulfuric acid aerosol production at 30 kilometers over Antarctica. David Hofmann, University of Wyoming. We will use 33 balloons of various sizes, instrumented with ozone-sondes to measure in detail vertical profiles of ozone and temperature from the ground to about 18 miles above the surface. These measurements should indicate where in the column changes the ozone is being destroyed. (S-289)

Upper atmosphere studies

For upper atmosphere, solar, and astronomical research, Antarctica is a unique platform from which researchers probe the Earth's upper atmosphere, its near- and far-space environment, and solar-terrestrial effects on man and the environment. The geomagnetic field lines that thread the Earth's magnetosphere intercept the Earth's surface and the ionosphere in polar regions. The effects of processes in the magnetosphere extend along these lines of force and are observed and studied at conjugate stations in Antarctica and the Arctic. Such simultaneous investigations enable scientists to learn more about the nature of the magnetosphere and the disturbances in this region that affect the Earth's atmosphere. Because the antarctic continent encompasses a wide range of geomagnetic latitudes, scientists can study the plasmapause (the internal magnetospheric boundary), the magnetospheric cusp, and the auroral zone. Solar and stellar astronomers are using the geographic South Pole for research because it offers continuous daylight (during the austral summer), high altitude, and low humidity. Data from these studies and others help describe how solar energy enters the outer terrestrial environment and reaches the atmosphere, how disturbances associated with the transfer of energy propagate to and affect the planet's surface, how space disturbances affect communications systems and power transmission, and how matter in the universe formed into galaxies and clusters of galaxies.

VLF wave-particle experiments on the magnetosphere and ionosphere from Siple Station. R.A. Helliwell, Stanford University. Controlled wave injection from the ground enables scientists to design new wave-particle interactions, as well as observe and analyze the function of these interactions. With these techniques scientists have acquired important quantitative information on the nature of wave-particle interactions in plasma under conditions that could not have been created in a laboratory. We will complete a 2-year investigation of wave-particle interactions in the magnetosphere and the ionosphere. Our objective is to understand natural and man-made magnetospheric very-low-frequency

(VLF) phenomena, VLF-wave propagation, wave-particle interactions in the Earth's magnetosphere, and magnetospheric thermal plasma structure and dynamics. We will use a new crossed dipole antenna configuration and a redesigned, upgraded transmitter control system for various experiments, including the effect of signal polarization on wave excitation in the magnetosphere, ground-to-ground propagation outside the plasmapause, the response of the magnetosphere as a function of injected signal level, the response to signals with varying degrees of coherence, and the effect of ionospheric structure on wave-injection experiments. To investigate VLF wave-induced precipitation in the ionosphere, we will search with a high-frequency radar for ionization-density changes and use the Siple transmitter signal to probe the earth-ionosphere propagation path to other antarctic stations. These experiments provide data that help us to better understand coherent radiation from plasma. These data are important to laboratory plasma physics and astrophysics, as well as magnetospheric physics. The results also can be applied to communications (both extremely-low-frequency and high-frequency systems), remote sensing of magnetospheric plasma, and modification of the magnetosphere and the ionosphere by wave-induced particle precipitation. (S-100)

Conjugate area studies of hydromagnetic wave and particle precipitation in dayside cusp regions. L. J. Lanzerotti, Bell Laboratories. Over the last decade, fluxgate magnetometers have been instrumental in studying hydromagnetic wave phenomena in the magnetosphere. At South Pole Station we use a magnetometer to examine the types of hydromagnetic waves produced in the cusp region of the magnetosphere. Hydromagnetic wave data from South Pole are combined with data from riometers, photometers, an ionosonde, and the all-sky camera to better understand the magnetospheric cusp region. Because South Pole provides outstanding climatic conditions for extended optical observations, we are able to correlate optical measurements with particle precipitation and hydromagnetic wave phenomena recorded by the magnetometer. We will continue experiments with a fluxgate magnetometer at Arrival Heights near McMurdo Station. (S-101)

Auroral imaging. S. B. Mende, Lockheed Palo Alto Research Laboratory. An image intensified all-sky camera, installed in 1982 at South Pole Station, has enabled us to monitor cusp auroral activity. This camera produces images of weak optical emissions at the latitude of the cusp, an important but poorly understood boundary region of the Earth's magnetosphere. For our data analysis we will use data from a two-channel photometer at Siple Station, correlative data from other projects at South Pole and Siple stations, and data from the

auroral imagery on the Dynamics Explorer satellite (DE-1). We are particularly interested in the extent to which aurora seen by DE-1 in the Northern Hemisphere mirror those observed at the South Pole. This austral summer we will inspect and do maintenance work on this equipment. The system will be operated and maintained by South Pole personnel during the austral winter. (S-104A)

Cosmic ray intensity variations. Martin A. Pomerantz, Bartol Research Foundation, University of Delaware. Cosmic rays provide a powerful tool for studying exotic astrophysical processes that occur on the Sun and in its far reaching atmosphere that controls space near Earth. Antarctic monitoring stations are crucial for probing interplanetary plasma dynamics through observations of variations in relativistic (over 1 gigaelectron-volt) galactic cosmic rays. At McMurdo and South Pole Stations, we will continue year-round observations of cosmic radiation and collaborate with the magnetospheric cusp program. To enhance our understanding of the solar physical processes that control the electromagnetic conditions in the Earth's environment, our data are used in conjunction with data from other ground-based instruments and spacecraft. (S-109A)

Galactic submillimetric emission in the southern hemisphere. Martin A. Pomerantz, Bartol Research Foundation, University of Delaware. At Amundsen-Scott South Pole Station we will try to detect fluctuations in the microwave background radiation, which is a remnant of the early universe. So far, measurements of this radiation have shown that it is remarkably uniform in all directions, but theorists suggest that microwave radiation must contain fluctuations, called anisotropy, that describe the initial clumping of matter during the formation of structure in the universe. We will use a 1-meter radio telescope, which was designed by Bell Laboratory researchers. The telescope can receive signals with wavelengths of about 3 millimeters, which is well below the limit predicted by theorists as necessary to record fluctuations in background radiation. To attain the required sensitivity, the telescope's receiver is cooled by liquid helium to three-tenths of a degree Celsius above absolute zero (-273.15°C). Because the telescope will be at the earth's axis, it will remain fixed and the earth's rotation will provide the scanning. Infrared observations made 2 years ago confirmed that the South Pole has the lowest water vapor content and "sky noise" on Earth. If this experiment is successful the South Pole could become a center for this type of cosmological research. (S-109C)

Riometry in Antarctica and conjugate regions. T. J. Rosenberg and D. L. Matthews, University of Maryland. The riometer (relative ionospheric opacity meter) provides continuous data on tempo-

ral and spatial variations of energetic precipitation and ionospheric perturbations. We use these data together with photometric, magnetic, and radiowave emission data to study physical processes associated with the transfer of solar wind energy to the magnetosphere and the upper atmosphere. At South Pole Station our investigations focus on the polar cusp, a dayside entry region for solar wind plasmas, and on the nightside polar cap region where magnetic substorm effects predominate. At McMurdo Station our studies relate exclusively to ionospheric phenomena in the polar cap. At Siple Station our objective is to investigate wave-particle interactions produced naturally by lightning (whistlers) and other natural very-low-frequency (VLF) emissions and artificially by the VLF transmitter. (S-111)

Ionosonde studies of the cusp ionosphere. F. T. Berkeley, *Utah State University*. Plasma instabilities and precipitation effects are produced in the ionosphere by the solar wind as it penetrates the magnetosphere through the magnetospheric cusp. Research has established that the cusp region, where particles with energies typical of magnetosheath plasma are present, is longitudinally elongated. It is composed of downstream plasma from the entry layer, upstream plasma that has been mirrored, and upward streaming ions and electrons of magnetospheric origin. The discovery of this magnetosheath-like plasma precipitation has drawn special attention to the dayside ionosphere; such precipitation causes the structure and dynamics of the dayside ionosphere to vary rapidly. Because these ionospheric disturbances cause electron density irregularities, we can measure these variations by means of an ionosonde (ionospheric sounder). These measurements provide year-round, detailed information on the structure and dynamics of the ionosphere. By operating an ionosonde at the South Pole, we can determine the ionospheric signature of the low-energy magnetosheath precipitation, estimate the size and location of the resulting ionospheric perturbation, and determine the latitudinal and longitudinal extent of the perturbation. Our investigation will provide a better understanding of the role of magnetosheath particle entry in the physics of the magnetosphere. We also will operate an all-sky camera, which records the dynamics of visible aurora by making exposures at a rate of one per minute. Visible auroral emissions are a direct manifestation of low-energy electrons precipitating into the dayside ionosphere. Because light emissions are generally weak, typical exposure times are usually several seconds. These color photographs will provide the necessary data to study the dynamics and morphology of the low-energy magnetosheath precipitation region. (S-122)

Automated photometry of selected stars at the South Pole. Frank Wood, *Univer-*

sity of Florida. Astronomical observations of celestial objects undergoing such changes as brightness, color, spectral type, or polarization of emitted radiation are hindered by daylight or starset interruptions. For photometric studies of binary star systems or observations of comets and asteroids this is particularly true. South Pole Station provides an ideal location for such observations, because in this region the elevations of stars do not vary and the world's longest nights exist. During the 1984 austral winter, we tested an automated, 8-centimeter telescope system to monitor photoelectrically four stars at several wave lengths. The nature of one star, a close binary system, is not understood, and we are gathering data on its light variation and changes in certain helium and carbon emissions. Observations of the other three stars are collected for comparison with the first star. During the 1985-1986 austral summer we installed a redesigned optical astronomical telescope, tested and aligned it, and surveyed the site for possible light pollution from South Pole station during the winter. We also tested the data retrieval system and developed procedures for transmitting selected data via satellite during the winter. This austral summer we will check the operation of the system and prepare it for continuing experiments throughout the 1987 winter. (S-123)

Support and logistics, 1986-1987

In late August 1986, flights to McMurdo Station began the 31st year of continuous U.S. support and research activities in Antarctica. Besides 12 scientists from two federal agencies and one university traveling to McMurdo Station to conduct a late winter study of ozone depletion, three other science groups and approximately 200 civilian and Navy support personnel participated in the early season flights.

Annually more than 1,000 people work on the continent as part of the support system for the U.S. antarctic program; another 400 work aboard Navy supply ships and U.S. Coast Guard icebreakers. Military personnel are members of the U.S. Naval Support Force Antarctica (NSFA), Antarctic Development Squadron Six (VXE-6), the U.S. Coast Guard, and other Navy or military units. The U.S. Air Force provides transport between New Zealand and McMurdo and a midwinter air drop to McMurdo and South Pole. Other support personnel are employees of a contractor, ITT/ Antarctic Services, Inc. (ITT/ANS). Navy personnel fly NSF-owned airplanes and U.S. Navy helicopters, oversee the operation of the supply ships, provide health care, long-range communications at McMurdo Station, weather fore-

casting, and some maintenance work at McMurdo; Coast Guard personnel operate the icebreakers. ITT/ANS employees provide support at McMurdo Station and operate Williams Field (McMurdo Station's skiway airfield on the Ross Ice Shelf), Amundsen-Scott South Pole, Siple, and Palmer stations, the research ship *Polar Duke*, and remote field camps.

Station activities

The construction of new facilities will be a focus for ITT/ANS employees at McMurdo Station during the 1986-1987 austral summer. They will begin to construct two dormitories and a vehicle maintenance and repair shop. The three-story dormitories will replace several temporary structures, some of which have been used since 1957. The buildings, each of which will house 138 persons, will be built of steel-frame, fire-resistant materials and will have fire detectors and sprinklers. The 21,000-square-foot, one-story repair shop will replace a vehicle maintenance facility destroyed by fire in 1981. In the interim, vehicles have been repaired in makeshift facilities. Construction of the three buildings is expected to be completed about February 1988. Other projects at McMurdo Station include site preparation for the new science laboratory and consolidation at one location of the station's satellite, high-frequency radio, and field party transceivers, which will be operated through a new dedicated computer.

After 3 years of construction, a new water distillation plant will begin operating at McMurdo Station this austral summer. The plant, which draws sea water from McMurdo Sound through a 2,500-foot heated, insulated pipe, can supply up to 80,000 gallons of fresh water per day, meeting all station needs. The water plant will use waste heat from McMurdo's diesel-driven electric generators, which are in a building next door, to distill the sea water. The new plant's capacity is double that of the current water plant, which will be retained for emergency use. With extreme conservation measures, McMurdo Station uses about 38,000 gallons of water each day during the summer.

In early November 1986 ITT/ANS employees will continue to renovate facilities at Amundsen-Scott South Pole Station. Among these projects are replumbing the station fuel lines and raising the clean air facility. This structure, built in the late 1970's, houses all of the atmospheric monitoring projects at the South Pole. When it was built, it was about 15 feet above the snow surface. Drifting snow has raised the snow surface to the floor of the building. ITT/ANS employees will raise the building about 12 feet to prevent it from being buried and to reduce the negative effects of surface winds on the air samplers.

Palmer Station will begin summer operations in early November when the *Po-*

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lar Duke arrives at the station with the relief crew and some science teams. Construction this austral summer will focus on renovating and adding to the biology laboratory. Science equipment aboard the *Polar Duke* will be upgraded before the ice-strengthened ship's first 1986-1987 cruise. New equipment includes a deep-sea coring system and a single-channel seismic digital data acquisition system.

At Siple Station, which begins summer operations in early November, upgrade of the ultra-low-frequency/very-low-frequency antenna will be completed. During the 1985-1986 austral summer the 26-mile-long dipole antenna was crossed by a second dipole antenna that extends 6.5 miles on each side. This austral summer two more 6.5-mile legs will be added. Because Siple will be closed from February 1987 to early November 1987, ITT/ANS employees also will prepare the station for an unattended winter.

McMurdo, Amundsen-Scott South Pole, and Palmer stations will be manned throughout the 1987 austral winter. Amundsen-Scott South Pole Station will begin winter operations on about 14 February and McMurdo Station on 20 February. At Palmer Station austral summer operations will end approximately 30 March, about 30 days earlier than usual; the early start of operations will enable NSF to continue to upgrade science equipment on *Polar Duke*. A winter cruise of *Polar Duke* to the Peninsula region is planned for June and July 1987 to support biologists studying winter ocean conditions.

Air support

The main deployment of support and science personnel to Antarctica is scheduled to begin on 1 October 1986. Between October and mid-December, 23 flights by U.S. Air Force C-141 Starlifter and 14 flights by Royal New Zealand Air Force (RNZAF) C-130 airplanes will augment flights by the antarctic program's ski-equipped Hercules (LC-130) airplanes. The Starlifters and RNZAF airplanes do not have skis and must land on McMurdo's sea-ice runway. By mid-December the sea ice deteriorates, and air operations are moved to the Williams Field skiway on the Ross Ice Shelf, where only ski-equipped airplanes can land. Besides flights between McMurdo Station and Christchurch, New Zealand, the program's LC-130 airplanes will transport personnel and materials to and from McMurdo, Siple, and Amundsen-Scott South Pole stations. During the 5-month austral summer, LC-130s are scheduled to fly 3,242 hours to support the stations and science projects in remote areas.

Another project planned for the 1986-1987 austral summer is to begin the recovery of all or part of an LC-130 that was damaged in 1971 in East Antarctica.

This season, a traverse from the French station on the coast of Adelie Land will bring necessary equipment and personnel to the crash site, known as D-59, to prepare the snow surface for landings by U.S. LC-130 airplanes. After the area has been prepared, support personnel from McMurdo Station will go to D-59 to begin digging out the airplane, which over the last 15 years has been buried by snow. The objective for this austral summer is to evaluate the condition of the airplane and its equipment and to determine whether or not the entire airplane can be salvaged.

UH-1N helicopters will support geology, glaciology, and biology field projects in the ice-free valleys of southern Victoria Land, the Allan Hills, and the Ross Island area. To support these projects the Navy helicopters will fly an estimated 610 hours between October 1986 and January 1987.

Ship support

The U.S. Coast Guard icebreaker *Polar Sea* and ice-strengthened ship *Glacier* will support the U.S. program in Antarctica during the 1986-1987 austral summer. Until 1986 *Glacier*, built in 1955, was classified as an icebreaker, but the Coast Guard found that the ship's hull had deteriorated to the extent that icebreaking would be impru-

dent. *Glacier* will support two geology projects and one biology project in the Antarctica Peninsula region during 5 weeks beginning in December. Afterwards the ship will sail to the Ross Sea region to support two science cruises.

Polar Sea will bring supplies and personnel to Palmer Station in late December and then travel to McMurdo Station to open a channel in McMurdo Sound sea ice. The channel break-in this austral summer is expected to be difficult because last year's sea ice did not leave the Sound. The icebreaker will remain in the Ross Island area after the channel break-in to escort the tanker *Paul Buck* and the supply ship *Green Wave* in and out of McMurdo Sound. It will also make three science cruises during February 1987 in the Ross Sea area.

Along the Antarctic Peninsula, science cruises will be made by the research ship *Polar Duke*. The 219-foot ice-strengthened ship is leased by the USA Antarctic Program to support research and to bring supplies and personnel to Palmer Station. *Polar Duke* will support biology, including three projects focusing on coastal ecosystems and processes, between November 1986 and March 1987.

A new data acquisition and display system for airborne research in Antarctica

The new Data Acquisition and Display System (DADS), designed by H. Terry and L. F. Radke for the National Science Foundation's research-configured, ski-equipped Hercules (LC-130R) airplane, replaces the Airborne Research Data System (ARDS), used in Antarctica on the LC-130R for more than a decade. This new system substantially improves operational flexibility and, because it is small and light, enables scientists to record data during LC-130R cargo flights.

DADS accepts data from all the permanent research sensors currently installed on the LC-130R (see table 1) and from additional analog and digital devices provided by researchers. The inputs include 16 analog channels, four 16-bit discrete ports, and two high-speed, multi-channel scaling-instrument ports that are used with particle counters. The data are recorded at 1 hertz on a high-capacity data cartridge, displayed on a monitor, and printed on a thermal printer. The DADS operator controls which data are displayed and printed.

DADS is comprised of a recording system and a display system (see figure 1). The recording system consists of instru-

ment interface circuits, two high-capacity tape drives for data, and a microcomputer. The system writes 1 kilobyte of data to the tape every second and can run continuously with little attention.

The recording system can operate independently of the display system. Because it communicates with the display computer through a standard serial port, the recording system easily can interface with any computer and can record voice comments. A computer-generated voice announces the time with each comment.

The display system consists of a computer with a keyboard, a CRT monitor, and a thermal printer. The computer executes a program that is stored in "read only" memory (ROM), runs automatically when there is power, receives data from the recorder, and processes data for display. Initially, a menu appears on the CRT and offers display options. The user can choose from three pre-programmed display formats or a "user format" with up to 26 data fields. The user can start and stop printing and choose which data are to be printed.

Table 1.
Permanent sensors aboard the LC-130R airplane.

<i>Parameter</i>	<i>Instrument</i>
Latitude	LTN-51 inertial navigational sector
Longitude	LTN-51 inertial navigational sector
Radar altitude	APN-194 radar altimeter
Pressure altitude	Garrett pressure transducer
Heading	C12 gyrocompass
True heading	LTN-51 inertial navigational sensor
True airspeed	computed
Track angle	LTN-51 inertial navigational sensor
Ground speed	" " " "
Drift angle	" " " "
Ground speed	APN-147 Doppler radar
Drift angle	" " " "
Wind direction	LTN-51 inertial navigational sensor
Wind speed	" " " "
Differential pressure	Pitot-static probe
Static pressure	Garrett pressure transducer
Angle of attack	Pitot-static probe
Angle of slip	Pitot-static probe
Total temperature	Total temperature sensor
Dew point	Thermoelectric dewpoint hygrometer
Cabin pressure	Rosemount transducer

The display system can also play back data tapes for post-flight data analysis. Normally, the display system ROM would be configured for a particular user before a project begins. Programs can be generated in the field and stored on cassettes, so modifications in the field are possible. The computer, an HP-9915A (which is functionally equivalent to an HP-85), is programmed in Basic.

DADS is easily transportable. Each component is packaged in an environmentally secure fiberglass enclosure with handles and removable covers. The enclosures contain shock-mounted equipment racks. In the normal operating configuration, the two boxes are stacked in the forward part of the airplane's cargo bay with a footprint of 0.61 meters by 0.66 meters.

Requests for the use of the DADS should be included in research proposals to the National Science Foundation. Operator training, limited software modification, supplies, and transcription of the formatted tapes into standard 9-track tapes can be provided at no cost to the user.

Development of the DADS was supported by National Science Foundation grant DPP 84-15197.

—H. Terry and L. F. Radke, Cloud and Aerosol Research Group, Atmospheric Sciences Department, University of Washington, Seattle, Washington 98195.

Foundation awards of funds for antarctic projects, 1 January 1986 to 30 June 1986

Following is a list of National Science Foundation antarctic awards made from 1 January 1986 to 30 June 1986. Each item contains the name of the principal investigator or project manager, his or her institution, a shortened title of the project, the award number, and the amount awarded. If an investigator received a joint award from more than one Foundation program, the antarctic program funds are listed first, and the total amount of the award is listed in parentheses. Award number for awards initiated by the Division of Polar Programs contain the prefix DPP, those initiated by the Division of Atmospheric Sciences contain the prefix ATM, and those initiated by the Division of Ocean Sciences contain the prefix OCE.

Biology and medicine

Chappell, Mark A. University of California, Riverside, California. Physiological ecology and energetics of thermal regulation in Adelie penguins. DPP 85-15357. \$65,113.

DeVries, Arthur L. University of Illinois, Urbana, Illinois. The role of glycopeptide and peptide antifreezes in the freezing avoidance of fishes. DPP 84-15266. \$100,797.

DeLaca, Ted E. Scripps Institution of Oceanography, San Diego, California.

Ecology of benthic foraminifera. DPP 83-05475. \$88,187.

Friedmann, E. Imre. Florida State University, Tallahassee, Florida. Study of the cryptoendolithic microbial ecosystem. DPP 83-14180. \$98,000.

Frost, Bruce W. University of Washington, Seattle, Washington. Antarctic marine ecosystem research at the ice-edge zone (AMERIEZ): Acoustic assessment of nekton and micronekton. DPP 84-20215. \$70,556.

Fryxell, Greta A. Texas A&M University, College Station, Texas. Antarctic marine ecosystem research at the ice-edge zone (AMERIEZ): Microalgae of the sea ice and water column. DPP 84-18850. \$64,167.

Garrison, David L. University of California, Santa Cruz, California. Antarctic marine ecosystem research at the ice-edge zone (AMERIEZ): Distribution of free-living protozoa. DPP 84-20184. \$90,000.

Green, William J. Miami University, Oxford, Ohio. Trace metal transport processes in Lake Vanda and the Onyx River. DPP 85-16465. \$97,027.

Hofmann, Eileen E. Texas A&M University, College Station, Texas. Collaborative research on a descent-ascent model of the eggs and larvae of krill. DPP 85-15486. \$74,813.

Holm-Hansen, Osmund. Scripps Institution of Oceanography, San Diego, California. Pilot investigation for research on antarctic coastal ecosystem rates and processes: Photobiology and primary production. DPP 85-19908. \$121,488.

- Hunt, George L. University of California, Irvine, California. The distribution of pelagic birds and their prey in the Scotia Sea. DPP 83-18464. \$85,223.
- Huntley, Mark E. Scripps Institution of Oceanography, San Diego, California. Research on antarctic coastal ecosystem rates and processes: Feeding, growth, and early development of krill, *Euphausia superba* Dana. DPP 85-17269. \$117,115.
- Karl, David M. University of Hawaii, Honolulu, Hawaii. Research on antarctic coastal ecosystem rates and processes: Microbiology and vertical flux component. DPP 85-18748. \$63,909.
- Nelson, David M. Oregon State University, Corvallis, Oregon. Antarctic marine ecosystem research at the ice-edge zone (AMERIEZ): Collaborative research on nutrient dynamics and phytoplankton productivity. DPP 84-20204. \$95,988.
- Palmisano, Anna C. University of Southern California, Los Angeles, California. The physiological ecology of sea-ice algae. DPP 84-15215. \$103,909.
- Quetin, Langdon B. University of California, Santa Barbara, California. Reproduction, feeding and swimming energetics, and egg and larval physiology of *Euphausia superba*. DPP 82-18356. \$37,197.
- Radtke, Richard L. University of Hawaii, Honolulu, Hawaii. Growth patterns in fishes. DPP 85-21017. \$25,604.
- Rivkin, Richard B. University of Maryland, Center for Environmental and Estuarine Studies, Cambridge, Maryland. Growth, photosynthesis, and carbon metabolism of marine phytoplankton. DPP 85-20278. \$37,148.
- Ross, Robin M. University of California, Santa Barbara, California. Collaborative research on a descent-ascent model of the eggs and larvae of krill. DPP 86-06440. \$24,995.
- Sidell, Bruce D. University of Maine, Orono, Maine. Characterization of energy metabolism in fish. DPP 85-16137. \$58,856.
- Siniff, Donald B. University of Minnesota, Minneapolis, Minnesota. Behavior and ecology of Weddell seals. DPP 83-18473. \$130,984.
- Smith, Walker O. University of Tennessee, Knoxville, Tennessee. Antarctic marine ecosystem research at the ice-edge zone (AMERIEZ): Collaborative research on nutrient dynamics and phytoplankton productivity. DPP 84-20213. \$46,980.
- Staley, James T. University of Washington, Seattle, Washington. Microbial and vertebrate chitin degradation in the marine environment. DPP 84-15069. \$54,321 (\$79,321).
- Torres, Joseph J. University of South Florida, Tampa, Florida. Antarctic marine ecosystem research at the ice-edge zone (AMERIEZ): Abundance, distribution, and energy utilization of micronekton and zooplankton. DPP 84-20562. \$127,053.
- Earth sciences**
- Askin, Rosemary A. Colorado School of Mines, Golden, Colorado. Cretaceous and Tertiary palynology of the James Ross Island Basin and western Ross Sea. DPP 83-14186. \$49,602.
- Behrendt, John C. U.S. Geological Survey, Reston, Virginia. Data compilation for map of magnetic anomalies, northern Victoria Land. DPP 86-07500. \$50,000.
- Cassidy, William A. University of Pittsburgh, Pittsburgh, Pennsylvania. Search for meteorites. DPP 83-14496. \$91,859.
- Collinson, James W. Ohio State University, Columbus, Ohio. Sedimentology of the Permian-Triassic Gondwana sequence in the central Transantarctic Mountains. DPP 84-18354. \$56,583.
- De Paolo, Donald, J. University of California, Los Angeles, California. Geochemical studies of Paleozoic granitic rocks of the central Transantarctic Mountains. DPP 83-16807. \$90,000.
- Elliot, David H. Ohio State University, Columbus, Ohio. Petrology of Ferrar and uppermost Beacon rocks, Beardmore Glacier region. DPP 84-19529. \$38,799.
- Elliot, David H. Ohio State University, Columbus, Ohio. The James Ross Island basin and the evolution of the Antarctic Peninsula. DPP 85-19080. \$50,579.
- Faure, Gunter. Ohio State University, Columbus, Ohio. Origin of basalt flows and sources of glacial deposits in the Transantarctic Mountains. DPP 84-17275. \$44,999.
- Feldmann, Rodney M. Kent State University, Kent, Ohio. Paleocology and paleobiogeography of decapod-rich assemblages on Seymour Island. DPP 84-11842. \$21,701.
- Grew, Edward S. University of Maine, Orono, Maine. Wollastonite in calc-silicate rocks of the east antarctic Precambrian shield and the role of carbon dioxide in granulite-facies metamorphism. DPP 84-14014. \$25,000.
- Hammer, William R. Augustana College, Rock Island, Illinois. Triassic vertebrates from the Beardmore Glacier area. DPP 85-11334. \$17,871.
- Knopoff, Leon. University of California, Los Angeles, California. Ultra-long period seismic and gravity observations at the South Pole. DPP 83-14945. \$57,740 (\$81,618).
- Kyle, Philip R. New Mexico Institute of Mining and Technology, Socorro, New Mexico. Volcanological studies of Mt. Erebus. DPP 85-19122. \$60,759.
- Lipschutz, Michael E. Purdue University, West Lafayette, Indiana. Trace elements in antarctic meteorites: Terrestrial and extraterrestrial applications. DPP 84-15061. \$80,000.
- Malin, Michael C. Arizona State University, Tempe, Arizona. Contemporary geomorphic processes in the ice-free valleys of southern Victoria Land. DPP 82-06391. \$50,000.
- Miller, Molly F. Vanderbilt University, Nashville, Tennessee. Sedimentology of the Permian-Triassic Gondwana sequence in the central Transantarctic Mountains. DPP 84-18445. \$37,996.
- Rees, Margaret N. University of Nevada, Las Vegas, Nevada. Origin and depositional setting of pre-Devonian, coarse-clastic sequences in the central Transantarctic Mountains: Evidence of one or more tectonic events. DPP 85-18157. \$67,907.
- Rowell, Albert J. University of Kansas, Lawrence, Kansas. Systematics, age, and significance of the Cambrian Shackleton Limestone fauna, central Transantarctic Mountains. DPP 85-19722. \$48,292.
- Rowley, Peter D. U.S. Geological Survey, Reston, Virginia. Regional geology of the southern Antarctic Peninsula. DPP 85-17151. \$23,500.
- Stump, Edmund. Arizona State University, Tempe, Arizona. Deformation during the Beardmore and Ross Orogenies, Nimrod Glacier area. DPP 84-18088. \$24,092.
- von Frese, Ralph R. Ohio State University, Columbus, Ohio. Lithospheric analysis of regional gravity and magnetic anomalies. DPP 83-13071. \$50,000.
- Webb, Peter-Noel. Ohio State University, Columbus, Ohio. Cenozoic micropaleontology and biostratigraphy of the Victoria Land basin. DPP 85-17625. \$59,380.
- Wogman, Nedwin A. BMI Batelle Northwest Laboratories, Richland, Washington. Measurement and interpretation of aluminum-26 in antarctic meteorites. DPP 85-14883. \$50,000.
- Woodburne, Michael O. University of California, Riverside, California. Mammalian paleontology, geology, and stratigraphy, Seymour Island. DPP 85-21368. \$74,378.

Ocean sciences

- Ackley, Stephen F. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Sea ice properties and processes. DPP 85-121728. \$117,412.
- Anderson, John B. Rice University, Houston, Texas. Marine geology of the continental margin. DPP 85-16908. \$86,342.
- Dick, Henry J. Woods Hole Oceanographic Institute, Woods Hole, Massachusetts. Petrology and tectonics of the circum-antarctic plate boundary. DPP 83-16490. \$133,853.
- Dunbar, Robert B. Rice University, Houston, Texas. Sinking and suspended particulate matter on the continental shelf. DPP 85-16911. \$33,678.
- Galloway, James N. University of Virginia, Charlottesville, Virginia. Marine sources of sulfate aerosol: Analysis program. DPP 84-19592. \$56,050.
- Gordon, Arnold L. Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York. Physical oceanography for the *Polarstern* 1986 winter Weddell Gyre expedition. DPP 85-02386. \$337,243.
- Gordon, Louis I. Oregon State University, Corvallis, Oregon. Nutrient and oxygen chemistry in winter. DPP 85-21472. \$18,375.
- Honjo, Susumu. Woods Hole Oceanographic Institute, Woods Hole, Massachusetts. Year-round particulate flux experiment in the central Weddell Sea. DPP 85-21471. \$18,375.
- Jacobs, Stanley S. Columbia University, Lamont-Doherty Geological Observatory, Palisades, New York. Ross Sea heat flux experiment. DPP 85-12540. \$74,634.
- Kennett, James P. University of Rhode Island, Graduate School of Oceanography, Narragansett, Rhode Island. Paleoenvironmental evolution of southern high-latitude oceans based on deep-sea sedimentary sequences. DPP 84-16687. \$80,449.
- Martinson, Douglas G. Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York. *Polarstern* winter 1986 expedition: Upper ocean structure. DPP 85-01976. \$82,634.
- Suess, Erwin. Oregon State University, Corvallis, Oregon. Thermal interaction between back-arc volcanism and basin sediments in the Bransfield Strait. DPP 85-12395. \$35,710 (\$75,710).
- studies in Terra Nova Bay. DPP 83-14613. \$14,736.
- Cronn, Dagmar R. Washington State University, Pullman, Washington. Analysis of atmospheric chemistry data from Palmer Station. DPP 85-15752. \$84,971.
- Hofmann, David J. University of Wyoming, Laramie, Wyoming. Sulfuric-acid aerosol production at 30 kilometers. DPP 85-15472. \$104,944.
- Lala, G. Garland. State University of New York, Albany, New York. Aerosol exchange processes in the Antarctic. DPP 85-16179. \$89,165.
- Morley, Bruce M. SRI International, Menlo Park, California. Airborne lidar study of aerosol distributions. DPP 84-17551. \$42,744.
- Murcay, David G. University of Denver, Denver, Colorado. Measurement of the column densities of water, fluorocarbons, and ozone during the austral winter. DPP 81-18005. \$39,711.
- Parish, Thomas R. University of Wyoming, Laramie, Wyoming. Surface winds of Antarctica. DPP 84-14695. \$60,646.
- Stearns, Charles R. University of Wisconsin, Madison, Wisconsin. Automatic weather stations: Operations and research. DPP 86-06385. \$106,992 (\$213,983).

Upper atmosphere

- Arnoldy, Roger L. University of New Hampshire, Durham, New Hampshire. Micropulsation research in the Antarctic and the Arctic. DPP 83-18632. \$54,490.
- Berkey, Frank T. Utah State University, Logan, Utah. All-sky camera observations of the dayside aurora from Amundsen-Scott South Pole Station. DPP 83-13428. \$36,000.
- Berkey, Frank T. Utah State University, Logan, Utah. A study of the mid-latitude ionospheric trough using high-frequency radar data. DPP 84-18173. \$41,644 (\$81,644).
- Eather, Robert H. Boston College, Chestnut Hill, Massachusetts. Imaging and photometry. DPP 86-02699. \$52,921.
- Engebretson, Mark J. Augsburg College, Minneapolis, Minnesota. Analysis of ultra-low-frequency pulsation data from ground and satellite magnetometers using a multiuser microcomputer system. ATM 86-06388. \$10,000 (\$35,400).
- Helliwell, Robert A. Stanford University, Stanford, California. Very-low-frequency wave-particle experiments on the magnetosphere and ionosphere from Siple Station. DPP 83-17092. \$318,374 (\$418,374).

Kinter, Paul M. Cornell University, Ithaca, New York. Application of full-wave calculations to very-low-frequency transmissions from Siple Station. DPP 86-00367. \$42,859.

Pomerantz, Martin A. Franklin Institute-Bartol Foundation, Newark, Delaware. Investigations of cosmic-ray intensity variations. DPP 83-00544. \$7,454.

Pomerantz, Martin A. Franklin Institute-Bartol Foundation, Newark, Delaware. Investigations of cosmic-ray intensity variations. DPP 85-16501. \$289,776.

Pomerantz, Martin A. Franklin Institute-Bartol Foundation, Newark, Delaware. The Sun and cosmic rays. ATM 83-03758. \$5,000 (\$27,354).

Rosenberg, Theodore J. University of Maryland, College Park, Maryland. Electron precipitation studies in Antarctica with imaging riometer systems. DPP 84-19272. \$145,000.

Wood, Frank B. University of Florida, Gainesville, Florida. Automatic photometry of selected stars at the South Pole. DPP 84-14128. \$2,908.

Glaciology

- Bockheim, James G. University of Wisconsin, Madison, Wisconsin. Late Cenozoic glacial history and soil development. DPP 83-19477. \$35,960.
- Denton, George H. University of Maine, Orono, Maine. Late Cenozoic glacial history and soil development. DPP 83-18808. \$117,017.
- Elmore, David. University of Rochester, Rochester, New York. Study of ice using radionuclides produced by cosmic rays. DPP 84-10467. \$27,000.
- Faure, Gunter. Ohio State University, Columbus, Ohio. Geological and geochemical study of Elephant Moraine, Allan Hills. DPP 83-17092. \$418,374.
- Fireman, Edward L. Smithsonian Institution, Astrophysical Observatory, Cambridge, Massachusetts. Radiometric ages and gas compositions of ice. DPP 85-16601. \$35,000.
- Hodge, Steven M. U.S. Geological Survey, Tacoma, Washington. Studies of internal layering and basal conditions in ice sheets using low-frequency ice radar. DPP 85-18618. \$71,054 (\$104,373).
- Jacobel, Robert W. St. Olaf College, Northfield, Minnesota. Studies of internal layering and basal conditions in ice sheets using low-frequency ice radar. DPP 85-17225. \$17,913 (\$27,141).
- MacAyeal, Douglas R. University of Chicago, Chicago, Illinois. Modelling ice-shelf flow, mass balance, and response to climate change. DPP 81-17235. \$52,767.

Meteorology

- Bromwich, David H. Ohio State University, Columbus, Ohio. Boundary layer



Weather at U.S. stations

Feature	May 1986					June 1986					July 1986				
	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	McMurdo	Palmer	Siple	South Pole
Average temperature (°C)	-18.7	- 4.7	-34.6	-61.1	-23.2	- 4.5	-35.8	-62.7	-25.4	- 6.9	-34.7	-25.4	- 6.9	-34.7	-59.4
Temperature maximum (°C) (date)	- 8.0 (1)	0.9 (4)	-17.5 (6)	-47.4 (30)	- 7.9 (17)	3.0 (13)	-23.8 (12)	-34.5 (12)	-10.0 (31)	4.9 (10)	-17.9 (3)	-10.0 (31)	4.9 (10)	-17.9 (3)	-33.7 (16)
Temperature minimum (°C) (date)	-28.9 (7)	-12.0 (29)	-52.6 (29)	-72.8 (17)	-40.4 (30)	-14.2 (8)	-48.6 (4)	-77.0 (28)	-38.1 (11)	-18.5 (23)	-54.2 (7)	-38.1 (11)	-18.5 (23)	-54.2 (7)	-73.1 (10)
Average station pressure (mb)	995.5	997.1	870.9	685.6	993.2	978.5	861.3	681.1	983.0	983.5	854.4	983.0	983.5	854.4	675.1
Pressure maximum (mb) (date)	1011.8 (13)	1014.0 (6)	885.2 (18)	697.2 (22)	1013.5 (12)	990.2 (1)	875.8 (7)	705.9 (4)	998.8 (22)	1004.6 (23)	872.6 (20)	998.8 (22)	1004.6 (23)	872.6 (20)	692.9 (18)
Pressure minimum (mb) (date)	968.7 (31)	976.5 (29)	851.0 (30)	666.0 (2630)	969.9 (1)	962.7 (30)	844.1 (4)	657.9 (12)	962.2 (14)	956.8 (10)	833.1 (485)	962.2 (14)	956.8 (10)	833.1 (485)	654.1 (263)
Snowfall (mm)	109.2	0.0	---	TRACE	99.1	353.1	---	TRACE	50.8	350.5	---	TRACE	50.8	350.5	TRACE
Prevailing wind direction	100°	030°	246°	090°	060°	090°	212°	070°	040°	330°	203°	040°	330°	203°	060°
Average wind (m/sec)	7.2	7.3	4.9	4.6	6.7	10.9	6.8	3.5	5.1	11.5	6.5	5.1	11.5	6.5	4.9
Fastest wind (m/sec) (date)	29.9 180° (24)	29.9 030° (15)	14.9 300° (17)	13.4 360° (5)	41.1 18° (6)	36.0 360° (12)	17.5 180° (29)	15.4 360° (12)	36.6 150° (14)	33.5 030° (11)	22.1 270° (30)	36.6 150° (14)	33.5 030° (11)	22.1 270° (30)	15.9 360° (7&15)
Average sky cover	8.0	0.8	3/10	0.1	6.1	8/10	6/10	0.3	4.3	8/10	6/10	4.3	8/10	6/10	0.4
Number clear days	0.0	6.1	15.3	27.0	6.0	1.9	6.3	21.0	14.0	3.5	9.5	14.0	3.5	9.5	18.8
Number partly cloudy days	14.0	2.8	5.3	4.0	15.0	4.6	5.5	5.4	9.0	3.1	4.3	9.0	3.1	4.3	4.7
Number cloudy days	16.0	22.1	9.3	0.0	9.0	23.5	8.5	3.6	8.0	23.4	9.8	8.0	23.4	9.8	7.5
Number days with visibility less than 0.4 km.	3.3	0.0	1.2	1.0	2.6	0.0	9.8	1.3	0.8	---	7.5	0.8	---	7.5	2.1

Prepared from information received by teletype from the stations. Locations: McMurdo 77° 51' S 166° 40' E, Palmer 64° 46' S 64° 3' W, Siple 75° 55' S 83° 55' W, Amundsen-Scott South Pole 90° S. Elevations: McMurdo sea level, Palmer sea level, Siple 1054 meters, Amundsen-Scott South Pole 2835 meters. For prior data and daily logs, contact National Climatic Center, Federal Building, Asheville, North Carolina 28801-2696 (704/259-0682).

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Moore, Richard K. University of Kansas, Lawrence, Kansas. Development of a modern radar system for probing ice sheets. DPP 83-00450. \$168,539.

Mosley-Thompson, Ellen. Ohio State University, Columbus, Ohio. Glaciological and climatological analysis of the past 2,000 years from ice cores. DPP 84-10328. \$117,000.

Moshiizumi, Kunihiko. University of California, La Jolla, California. Study of ice using radionuclides produced by cosmic rays. DPP 84-09526. \$27,000.

Spilhaus, A. F. American Geophysical Union, Washington, D.C. Chapman conference on fast glacier flow: Ice streams and surging and tidewater glaciers. DPP 85-21012. \$5,000 (\$10,000).

Stuiver, Minze. University of Washington, Seattle, Washington. Oxygen-isotope analysis of ice cores. DPP 84-00574. \$146,899.

Webb, Peter-Noel. Ohio State University, Columbus, Ohio. Stratigraphy, paleontology, and sedimentology of the Sirius Formation, Beardmore Glacier region. DPP 84-20622. \$123,614.

Whillans, Ian M. Ohio State University, Columbus, Ohio. Ice dynamics on the Marie Byrd Land slope. DPP 81-17235. \$52,767.

Whillans, Ian M. Ohio State University, Columbus, Ohio. Studies of internal layering and basal conditions in ice

sheets using low-frequency ice radar. DPP 85-19550. \$11,222 (\$17,004).

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NSF photo by Ann Hawthorne.

Since 1978 biologists have been studying cryptoendolithic microorganisms—bacteria, algae, and lichen that live in rock fissures in Antarctica's ice-free regions. Near Linnaeus Terrace (77°36'S 161°5'E) on the southern slope of Wright Valley, a biologist sets up equipment that will record environmental changes and transmit these data to a satellite, which will relay the data to centers in the United States. These data will help biologists understand how endolithic organisms survive the extended darkness and extremely low temperatures of the austral winter.

Terrestrial biology in Antarctica since the International Geophysical Year

The growth of biology

It may seem paradoxical to use the International Geophysical Year (IGY) of 1957-1958 as a milestone for the progress and growth of the life sciences, but life science research in Antarctica did in-

crease following this period. The pattern of international cooperation established during the IGY has been continued through the principles of the Antarctic Treaty, which entered into force in 1961. These principles, combined with the

guidance provided by the international science community through the Scientific Committee on Antarctic Research (SCAR) within the International Council of Scientific Unions (ICSU) in 1957 (Llano, 1978), have contributed to the rise in not only life science research but all research in Antarctica. The growth of U.S. antarctic research was aided by the formation of the Committee for Polar Research of the National Academy of Sciences in 1958. This committee, which is now called the Polar Research Board, advises the National Science Foundation and recommends research.

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In 1960 the United States Antarctic Research Program (USARP) was established at the National Science Foundation (Llano, 1978). Although post-IGY growth of antarctic science was not unique to the United States, USARP and the military Operation Deep Freeze support group provided the infrastructure, field facilities, and logistics base upon which modern U.S. antarctic life science research depends. All of this is rooted in the IGY despite the IGY's inanimate name. Moreover, some life science research was carried out by IGY scientists. Carl R. Eklund, after whom the Eklund Biological Center at McMurdo Station is named and who was scientific leader of Wilkes Station during the IGY, initiated bird banding and seal banding studies and measured the temperature of incubating skua eggs by radiotelemetry (Llano, 1973).



Editor: Winifred Reuning

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History of antarctic life sciences

The crews of the Cook (1772-1775) and Bellinghausen expeditions (1819-1821), as well as individuals associated with the sealing industry that followed these early cruises, made the first biological observations near Antarctica. Most early observations naturally tended to concern marine organisms or such land-based predators as seals and penguins. Observations on the less accessible continent and its small terrestrial fraction came later. Even today the balance in life science studies still favors marine environments. This is not surprising since only 2.4 percent of the antarctic continent is land (figure 1 and Budd, 1986), which is often too dry and too cold to support much soil and life (Heap and Holdgate, 1986). The oceans by contrast are vast and uninterrupted around the continent, are relatively more hospitable than the land, and have an abundance of life (Deacon, 1984).

Several collections of terrestrial organisms were made at the end of the nineteenth century and the beginning of this century by Belgian, English, French, German, Norwegian, Scottish, and Swedish expeditions (Budd, 1986). Many of these were to the sub-Antarctic islands and the Antarctic Peninsula. Up to this point the role of the United States in antarctic research was modest (Llano, 1973); however, between 1920 and 1948, there were 10 U.S. expeditions (Bertrand, 1971). During this period and up to the IGY knowledge about terrestrial flora, fauna, and ecology gradually accumulated. By the time of the IGY biological publications were more numerous than any other single branch of science and comprised one-fifth of the existing antarctic literature.

The following statements on antarctic biological literature are derived from Budd (1986). Currently biology papers comprise perhaps a third of antarctic literature. The U.S. contribution to biology literature has shifted in recent years. In the early 1960s, the U.S. contributed about 28 percent and was about equal to that of the Soviet Union. This proportion has now dropped in both countries, and U.S. biological contribution is about 11 percent of the total. The reasons for this are the greater number of contributing countries and, perhaps more striking, an increased emphasis in disciplines such as glaciology and geology, which have increased in productivity since the IGY. The star performer in antarctic biology, and especially in biology of terrestrial systems, is the United Kingdom. British antarctic scientists currently publish much more frequently than their U.S. counterparts, although several of these United Kingdom publications concern the islands in the maritime sub-Antarctic rather than the Antarctic.



NSF photo by Ann Hawthorne.

A biologist extracts samples of endolithic organisms from colonized rocks in Wright Valley, southern Victoria Land. These samples will be used in laboratory studies of how these microbiota respond to changing light intensity.

Fewer papers are published on terrestrial biology than marine biology; this reflects the present balance of research funding. The rate of publication over the last 5 years in most antarctic sciences has been steady and does not seem to be accelerating (Budd, 1986). Limited funding and logistics are probably the reason for this trend. In this respect, antarctic science contrasts with arctic science. The more urgent and more rapid development of arctic resources and the proximity of the Arctic to population centers connected by contiguous land masses partially explain this difference.

Antarctic life sciences have progressed through the same phases as life sciences elsewhere—exploration, reconnaissance, and, then, cataloging and description (taxonomy) of what was found. These phases, in turn, are followed by investigation of how an organism got there (origin and systematics) and of how the organism or system functions (physiology). Today research emphasizes the latter phase and involves mechanisms of organism adaptation (Parker, 1978) and flows of energy and matter within ecosystems (Siegfried, Condy, and Laws, 1985). Nevertheless, survey, description, paleoecology, biogeography, and evolutionary studies should continue to remain in future research programs.

Other trends have occurred. Generally, research has progressed since the IGY from the single investigator working



in one or a few localities through groups of specialists or multidisciplinary teams to interdisciplinary teams. This trend also has been accompanied by more international cooperation and a shift in scale from single localities to regional and now global and biospheric considerations. The successful International Biological Program (IBP) from 1967 to 1974 (Blair, 1977) demonstrated how valuable interdisciplinary teams are in studies of complex systems. The Tundra Biome program of IBP involved both antarctic and arctic terrestrial biologists and led to an exchange of many new ideas and the production, through synthesis, of other ideas (Llano, 1978; Bliss et al, 1981).

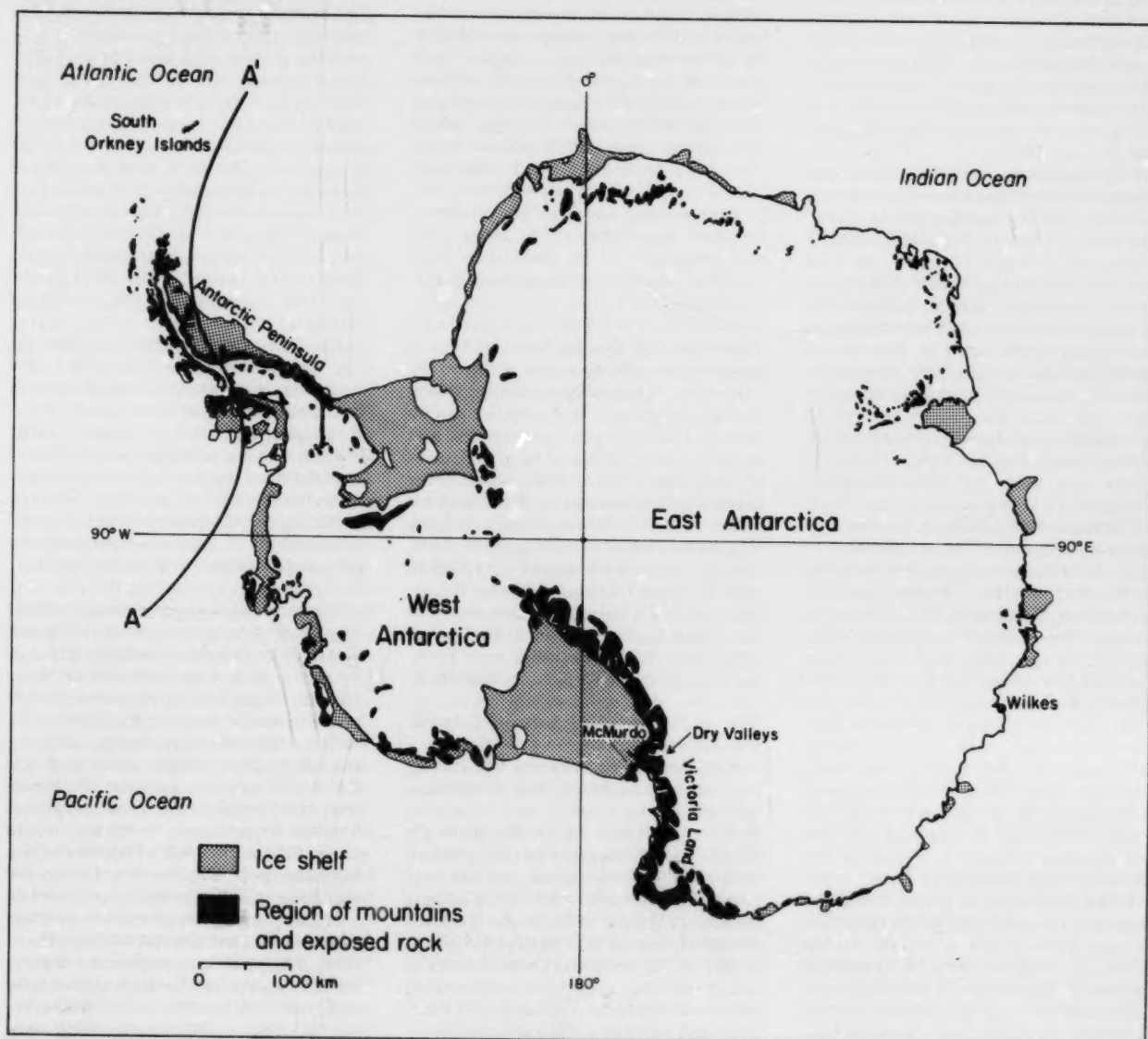
SCAR has promoted international cooperation in science. For example, it was the vehicle for planning the international marine life sciences program, BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks) over the last decade. SCAR has permanent working groups (including one on biology) that coordinate science and logistic programs, organize symposia, and plan antarctic contributions to global research programs. Central to SCAR is the concept of free international exchange of plans and results among scientists in the conviction that understanding the complexities of natural systems requires many observations and many minds.

Histories of the life sciences in Antarctica can be found in Llano (1978), Deacon (1984), Walton and Bonner (1985), Rutford (1986), and Budd (1986).

Antarctic terrestrial ecosystems

Terrestrial life sciences in Antarctica are important beyond Antarctica. Although the continent is at an end of the Earth, it is not isolated from the rest of the biosphere. The Antarctic is an ideal laboratory for study of how organisms adapt and ecosystems function in simple and extreme environments with minimal amounts of energy, water, and nu-

Map of Antarctica showing generalized regions of mountains and summer-snow and ice-free ground where terrestrial and inland water ecosystems can develop (after Tedrow and Ugolini in Tedrow, 1966). A-A is the biogeographic boundary between the maritime Antarctic to the West and the continental Antarctic to the East (from Pickard and Seppelt, 1984).



trients. The assertion that the antarctic terrestrial environment is "the least favorable for terrestrial life on Earth" (NSF 1980, p. 3-7) seems justified. Yet, some organisms have adapted to this environment, although biotic diversity is much less than in areas of equivalent size in other land masses and environments. The low diversity not only relates to the climatic severity but also to geographic isolation of the continent and the recent age of its modern terrestrial biota. Non-vascular cryptogams and invertebrates contribute most to the diversity of the terrestrial flora and fauna. There are some 600 species of lower plants, such as algae, mosses, and lichens, and some 150 species of invertebrates such as rotifers, nematodes, collembola, and mites. Only two vascular plant species are found in Antarctica.

The terrestrial biota has several endemic species but few endemic genera, suggesting that it is evolutionarily young and derived from stocks of temperate regions (Rudolph, 1966). In this respect the marine biota differ; their larger set of endemic species and genera is interpreted as indicating greater stability and age of the marine environment (Benninghoff and Bonner, 1985).

Biogeographers recognize two broad regions within Antarctica—the maritime Antarctic and the continental Antarctic. The latter is often further subdivided by geologists and glaciologists into East Antarctica and West Antarctica (figure 1). The maritime Antarctic includes the Antarctic Peninsula and islands to the north such as the South Sandwich and South Orkney islands. The continental Antarctic includes the coastal fringe of East Antarctica, the glaciers and inland mountains, and the interior of the continent (Lewis-Smith, 1984). These regions and their subdivisions have characteristic climates, fauna, and flora.

Climate is the dominant determinant of life system type. The maritime Antarctic is warmer and moister than the continental Antarctic. The maritime Antarctic averages about -10°C in winter; in summer the average temperatures exceed 0°C by only a little for 1 to 4 months. Precipitation ranges between 35 and 50 centimeters water equivalent per year with much of it falling as rain in summer. The continental Antarctic is extremely cold and dry all year. Only on the coastal fringes do mean temperatures go above freezing for more than a few days or weeks. Here rain is rare and the total precipitation is between 10 and 15 centimeters water equivalent.

In the maritime Antarctic, terrestrial organism diversity and productivity decreases from north to south. In the north, a complete cover of vegetation may occur in favorable places. This vegetation may be comprised of moss carpets or the two vascular plants. In some loca-

tions the balance of moss growth and decay may be such that peat accumulates. In the south, the two vascular plants are less frequent but still occur, closed stands of vegetation are rare, and peat does not accumulate. In the continental Antarctic, vascular plants do not occur nor does peat accumulate. Here, terrestrial ecosystems are restricted to mountains and nunataks where some surfaces become free of snow and ice and to the coastal areas where beaches occur sporadically and glacier forelands are found. Southern Victoria Land has extensive snow- and ice-free valleys, but most of the continental Antarctic is covered permanent by snow and ice. Apart from patches of algae in melting snow and occasional microorganisms and stray birds, the region is devoid of life.

The terrestrial communities are patchy and heterogeneous. Nevertheless, whenever and wherever the appropriate resources for life exist then the site is occupied. For example, in southern Victoria Land's icefree valleys endolithic lichens live beneath rock surfaces (Friedman, 1982); Adelie penguins occupy pebble beaches of sufficient size and nearness to the ocean (Penney, 1968); and mosses grow with sufficient water, dissolved nutrients, and sunshine (Green et al., 1967). The patchiness may be further exaggerated by the tendency for some organisms—for example, seals and penguins—to be present in high densities with few other species.

Three research themes and some recent achievements

Ample evidence of the maturing of terrestrial life sciences in Antarctica can be seen in two in-depth compilations and reviews (Laws, 1984; and Siegfried, Condy, and Laws, 1985). Both books cover marine and terrestrial systems and together exceed 1,500 pages including voluminous references. The first, *Antarctic Ecology*, updates an earlier compilation with the same title and publisher (Holdgate, 1970). The new book demonstrates how much has been added to our knowledge since 1970. The other new book, *Antarctic Nutrient Cycles and Food Webs*, covers the state of knowledge of energy flow and biogeochemistry in antarctic ecosystems.

Adaptation to extreme cold. The mechanisms of adaptation to extreme cold are of great interest, and there is no better place than Antarctica to study them. Paradoxically, no adaptation unique to antarctic organisms has ever been demonstrated. The adaptations shown are similar to those of organisms in high alpine, arctic, and desert regions. Parker (1978) reviewed these terrestrial adaptations ranging from acclimation, inherited tolerance, physiologic tolerance, and avoidance. One spectacular ex-

ample of adaptation is the ability of an antarctic springtail to withstand freezing at -50° to -60°C (Pryor, 1962). The exact mechanism for this freezing resistance is unknown but probably involves some natural antifreeze agents such as polyhydric alcohols and sugars in the body and cell tissues similar to other cold tolerant insects (Baust and Morrissey, 1977). Block and others (1978) report glycerol in an antarctic mite that survived supercooling to -30°C .

The claim that unique antarctic adaptations have yet to be demonstrated will depend on definitions and level of focus within the hierarchy of biological organization. Nevertheless, this reviewer is not convinced that truly unique adaptations have been demonstrated.

Conservation. Antarctica is still relatively pristine in spite of extensive human occupation during the sealing and whaling era and since the IGY. The low resilience of terrestrial systems in this extreme environment following disturbance makes them particularly vulnerable (Heap and Holdgate, 1986). Many impacts will be cumulative over time and, with the prospects of increased tourism and even a mineral industry, steps are being taken for better protection. The two most notable of these are the preparation of environmental impact statements (Parker and Holliman, 1978, and NSF, 1980) and the setting aside of specially protected areas (Bonner and Lewis-Smith, 1985) by the Antarctic Treaty with the advice of SCAR.

The spread of pollution, another aspect of conservation, has shown that Antarctica is not isolated from the rest of the Earth. Scientists have found polychlorinated biphenyls in antarctic birds (Risebrough and Carmigniani, 1972) and have detected low levels of radioisotopes from nuclear testing in snow (Bonner, 1984). These manmade substances come from outside of Antarctica primarily by long distance atmospheric transport.

Martian analogs for extraterrestrial life. Many scientists consider southern Victoria Land's ice-free valleys similar to a present or past environment of Mars. That the Viking Lander did not detect life on Mars was no surprise to scientists familiar with the microbiology of these antarctic valleys, where many soils are too dry or saline to support life (Cameron, 1971) and where some cryptoendolithic organisms are found inside rocks (Friedman, 1982). Planners of the sampling program for any future life searching mission to Mars will need to consider the habitats of these organisms (Friedman and Ocampo-Friedman, 1984). The endolithic habitat is a favorable microscopic niche in an otherwise unfavorable macrocosm. Bacteria, yeasts, fungi, cyanobacteria, algae, and

lichens just beneath the surface of porous rocks occur in these extremely simple ecosystems. (Friedman, 1982).

Future research

Laws (1984) estimates that fewer than 2,000 biologists (marine and terrestrial) have worked on this vast continent. He points out that this is fewer biologists than have worked in some English-speaking countries. Thus, despite much highly acclaimed research, antarctic life science still has a long way to go. The list of reasons given earlier for studying antarctic life science remains valid. Most of the past and recent thrusts in antarctic terrestrial life science—survey, taxonomy and biogeography, adaptation and life-history patterns, biogeochemical cycling and system coupling, ecosystem dynamics, and monitoring (Polar Research Board, 1983)—are still far from complete. In particular, field research in Antarctica will continue to be critical because no adequate substitute has been found for *in situ* research, despite progress with controlled environmental chambers. Even the search for analog conditions for extraterrestrial life and studies of conditions for cryopreservation of cell lines will benefit by *in situ* investigations. In fact, Brown's (1906) statement (in Lewis-Smith, 1984) remains true today, "it is...extremely desirable that...physiological and morphological questions should be studied on the spot, indeed, the impracticability of satisfactory investigation in any other circumstances is most obvious."

Most terrestrial biology is likely to remain focused on whole organisms and small local systems for a time. Regional and even continent-wide studies would not be excluded but the state of our knowledge and the spatially variable and heterogeneous nature of antarctic terrestrial systems seem to assure that much is still undiscovered about individual organisms, populations, and local ecosystems. Terrestrial systems have a greater spatial variability and heterogeneity than the more fluid systems of ocean, atmosphere, and ice. Further, unlike the fluid systems, antarctic terrestrial systems are constrained and unlikely to affect significantly global processes. Conversely, we might expect that global changes and changes in the adjacent systems of ice, air, and water, to which terrestrial systems are linked may have a considerable effect on terrestrial ecosystems; Hurel (1985) has called for further study of how systems couple.

The following topics are selected from recent research papers as suggestions for future directions. Zumbege (1979) calls for a further inventory of flora, fauna, and mapping of soils, landforms and

communities. Lewis-Smith (1984) suggests that taxonomic revisions, especially of the nonvascular cryptogamic macroflora are needed. Continued data gathering and monitoring of terrestrial systems both year-round and long-term have been called for by Laws (1985) because such data are essential to understanding function and dynamics. Laws also suggests comparative studies not only of polar systems but also among polar, temperate, and tropical systems.

Research procedures worked out for the long-term ecological research (LTER) program of the National Science Foundation, which focuses on major U.S. ecosystems (Callahan, 1984), may be appropriate for antarctic terrestrial biology. System monitoring can assess human impact (Benninghoff and Bonner, 1985) and the effect of global change on local systems (Roots, 1986). No major terrestrial models have yet been made for an antarctic ecosystem, perhaps because we do not yet understand the systems well enough, but models can be useful for conceptualizing the systems and, if reliable, for predicting impacts or environmental changes that might occur. Laws (1985) and Lewis-Smith (1985) describe structured planning for antarctic terrestrial ecosystem research.

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References

- Baust, J.G., and Morrissey, R.E. 1977. Strategies of low temperature adaptation. *Proceedings of the XV International Congress of Entomology*. 173-184.
- Benninghoff, W.S., and Bonner, W.N. 1985. *Man's Impact on the Antarctic Environment*. Scientific Committee on Antarctic Research (SCAR)/International Council of Scientific Unions (ICSU). Cambridge, United Kingdom: Scott Polar Research Institute. 56p.
- Bertrand, K.J. 1971. Americans in Antarctica 1775-1948. *American Geographical Society, Special Publication*, 39. New York: American Geographical Society. 554p.
- Blair, W.F. 1977. *Big biology: the US/IBP*. Stroudsburg, Pennsylvania: Dowden, Hutchinson and Ross, Inc. 261p.
- Bliss, L.C., O.W. Heal, and J.J., Moore. 1981 (eds.) *Tundra ecosystems: a comparative analysis*. Cambridge, England: Cambridge University Press. 813 p.
- Block, W., S.R. Young, E.-M. Conradi-Larsen, and L. Somme. 1978. Cold tolerance of two antarctic terrestrial arthropods. *Experimentia*, 34:1166-1167.
- Bonner, W.N. 1984. Conservation. In *Antarctic ecology*, R.M. Laws (ed.) London, United Kingdom: Academic Press. 822-850.
- Bonner, W.N., and R.I. Lewis-Smith. 1985. *Conservation areas in the Antarctic*. Scientific Committee on Antarctic Research (SCAR), International Council of Scientific Unions. Cambridge, United Kingdom: Scott Polar Research Institute. 299p.
- Brown, R.N.R. 1906. Antarctic botany; its present state and future problems. *The Scottish Geographical Magazine*. 22:473-484.
- Budd, W.F. 1986. The Antarctic Treaty as a scientific mechanism (post-IGY)—contributions of antarctic scientific research. In *Antarctic Treaty system: an assessment*, Washington, D.C.: National Academy Press. 87-101.
- Callahan, J.T. 1984. Long-Term Ecological Research. *BioScience* 34(6):363-367.
- Cameron, R.E. 1971. Antarctic soil microbiology and ecological investigations. In *Research in the Antarctic*, L.O. Quam and H.D. Porter (eds). Washington, D.C.: American Association for the Advancement of Science.
- Deacon, G. 1984. *The antarctic circumpolar ocean*. Cambridge, England: Cambridge University Press. 180p.
- Friedman, E.I., and R. Ocampo-Friedman. 1984. The antarctic cryptoendolithic ecosystem: relevance to exobiology. *Origins of Life*. 14:771-776.
- Friedman, E.I. 1982. Endolithic microorganisms in the antarctic cold desert. *Science*. 215:1045-1053.
- Greene, S.W., J.L. Gressitt, D. Koob, G.A. Llano, E.D. Rudolph, R. Singer, W.C. Steere, and F.C. Ugolini. 1967. Terrestrial life of Antarctica. *Antarctic*

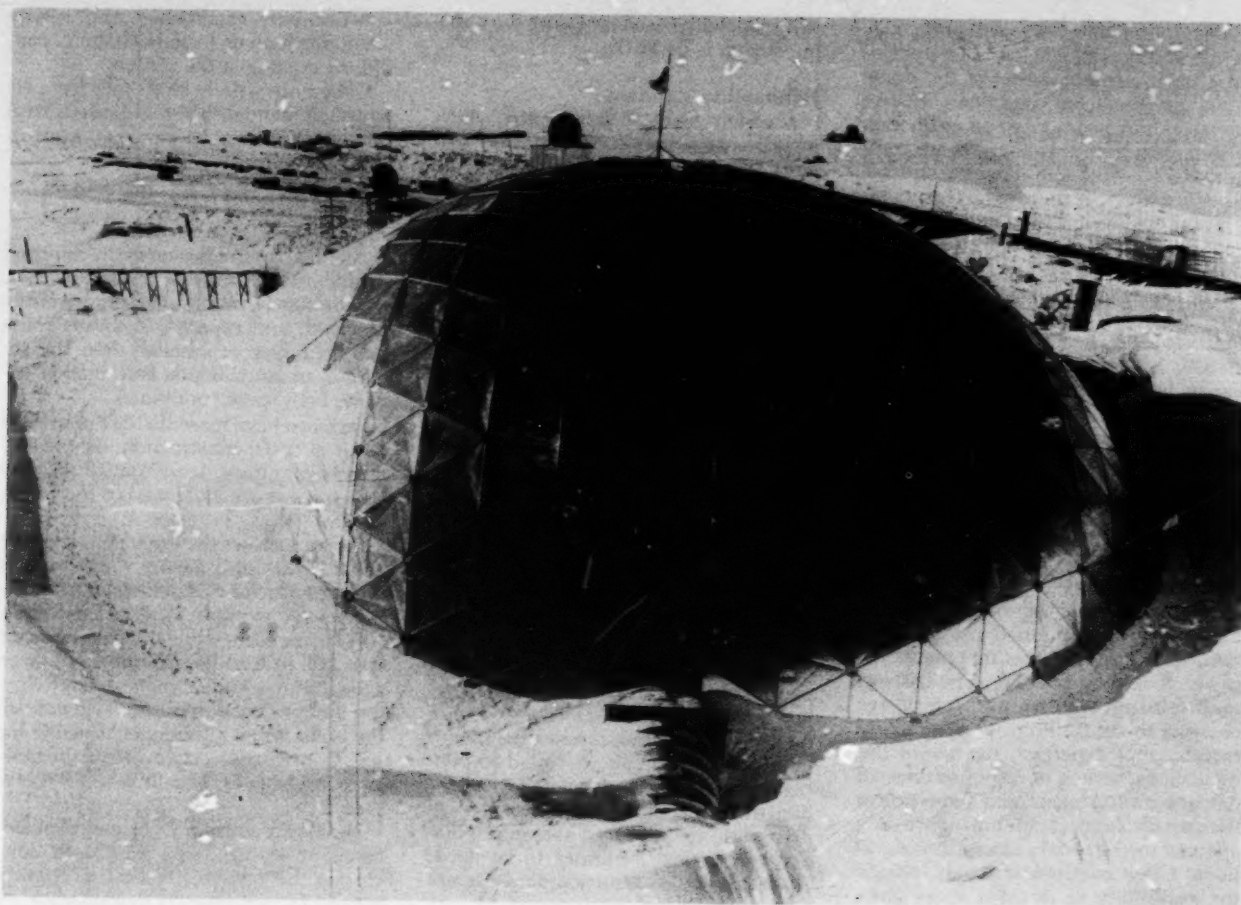
- map folio series. 5. New York, New York: American Geographical Society.
- Heap, J.A., and M.W. Holdgate. 1986. The Antarctic Treaty as an environmental mechanism—An approach to environmental issues. *Antarctic Treaty system: an assessment*. Washington, D.C.: National Academy Press. 195-210.
- Holdgate, R.M. (ed). 1970. *Antarctic Ecology*. London, United Kingdom: Academic Press. 998p.
- Hureau, J.C. 1985. Interactions between antarctic and subantarctic marine, freshwater and terrestrial organisms. In *Antarctic nutrient cycles and food webs*, W.R. Siegfried, P.R. Condry, and R.M. Laws (eds). Berlin, Federal Republic of Germany: Springer-Verlag. 626-629.
- Laws, R.M. (ed.) 1984. *Antarctic ecology*, London, United Kingdom: Academic Press. 850p.
- Laws, R.M. 1985. Summary and conclusions. In *Antarctic nutrient cycles and food webs*, W.R. Siegfried, P.R. Condry, and R.M. Laws (eds.). Berlin: Federal Republic of Germany: Springer-Verlag. 626-629.
- Lewis-Smith, R.I. 1984. Terrestrial plant biology of the sub-antarctic and antarctic. In *Antarctic ecology*, R.M. Laws (ed.) London, United Kingdom: Academic Press. 61-162.
- Lewis-Smith, R.I. 1985. Nutrient cycling in relation to biological productivity in antarctic and sub-antarctic terrestrial and freshwater ecosystems. In *Antarctic nutrient cycles and food web*, W.R. Siegfried, P.R. Condry, and R.M. Laws (eds.), Berlin, Federal Republic of Germany: Springer-Verlag. 138-155.
- Llano, G.A. (ed). 1972. *Antarctic terrestrial ecology*. In *Antarctic Research Series*, No. 20. Washington, D.C.: American Geophysical Union. 322p.
- Llano, G.A. 1973. A survey of antarctic biology: life below freezing. *Frozen future*. Smith, R.S., and P.M. Smith. (eds.), Quadrangle Books.
- Llano, G.A. 1978. Polar research: A synthesis with special reference to biology. In *Polar research - to the present and future*, M.A. McWhinnie (ed.), Boulder, Colorado: Westview Press. 27-53.
- National Science Foundation. 1980. *U.S. Antarctic Program final environmental impact statement*. Washington, D.C.: National Science Foundation.
- Parker, B.C. 1978. Terrestrial adaptations in polar regions. In *Polar research to the present and the future*, M.A. McWhinnie (ed.). Boulder, Colorado: Westview Press. 203-229.
- Parker, B.C. (ed.) and M.C. Holliman, (tech. ed.), 1978. *Environmental Impact in Antarctica*. Blacksburg, Virginia: Virginia Polytechnic Institute and State University.
- Penney, R.L. 1968. Territorial and social behavior in the Adelie penguin. In *Antarctic bird studies. Antarctic research series*, Vol. 12, O.L. Austin, Jr. (ed.). Washington, D.C.: American Geophysical Union. 83-131.
- Pickard, J., and R.D. Seppelt. 1984. Phytogeography of Antarctica. *Journal of Biogeography*, 11:83-102.
- Polar Research Board, 1983. *Research emphasis for the U.S. Antarctic Program*. Commission on Physical Sciences, Mathematics, and Resources, National Research Council. Washington, D.C.: National Academy Press. 52p.
- Pryor, M.E. 1962. Some environmental features of Hallett Station, Antarctica, with special reference to soil arthropods. *Pacific Insects*, 4:681-728.
- Risebrough, Robert W., and Gary M. Carmigniani. 1972. Chlorinated hydrocarbons in antarctic birds. In *Conservation problems in Antarctica*, Bruce C. Parker (ed.). Lawrence, Kansas: Allen Press.
- Roots, E.F. 1986. The role of science in the Antarctic Treaty System. In *Antarctic Treaty system: an assessment*. Washington, D.C.: National Academy Press. 169-191.
- Rudolph, E.D. 1966. Terrestrial vegetation of Antarctica: Past and present studies. In *Antarctic soils and soil forming processes, Antarctic Research Series*, Vol. 8, J.C.F. Tedrow (ed.). Washington, D.C.: American Geophysical Union.
- Rutford, R.H. 1986. Summary of science in Antarctica prior to and including the International Geophysical Year. In *Antarctic Treaty system: an assessment*. Washington, D.C.: National Academy Press.
- Siegfried, V.W., P.R. Condry, and R.M. Laws (eds.). 1985. *Antarctic nutrient cycles and food webs*. Berlin, Federal Republic of Germany: Springer-Verlag. 700p.
- Tedrow, J.C.F. (ed.). 1966. *Antarctic soils and soil forming processes, Antarctic Research Series*, Vol. 8. Washington, D.C.: American Geophysical Union. 177p.
- Walton, D.W.H., and Bonner, W.M. 1985. History and exploration in antarctic biology. In *Key environments—Antarctica*. W.N. Bonner and D.W. Walton (eds). Oxford, United Kingdom: Pergamon Press. 1-20.
- Zumberge, J.H. (ed). 1979. *Possible environmental effects of mineral exploration and exploitation in Antarctica*. Cambridge, United Kingdom: Scientific Committee on Antarctic Research. 50p.

Assessing the usable life of an antarctic station

When to divert substantial funding from other projects and needs to build new facilities is a difficult decision. Antarctic construction planners must consider many factors, such as the amount of time needed for transporting equipment and materials from distant locations, a short construction season, special design considerations, and environmental hazards. Presently, the USA Antarctic Program is considering when to replace Amundsen-Scott South Pole

Station. The Naval Civil Engineering Laboratory (NCEL) has been asked to provide some of the information necessary to make this decision.

The first year-round station at the geographic South Pole was built for the International Geophysical Year (1957-1958). After 10 years, this station was covered with 6 meters of snow. Under the weight of the snow the buildings distorted, and the station's structural and operational safety deteriorated. Re-



NSF photo by Ann Hawthorne.

The geodesic dome of Amundsen-Scott South Pole Station was completed 13 years ago. Although it is now 3 years past its planned usable life, engineers from the Naval Civil Engineering Laboratory found after analyzing its structural safety that it is still sound.

cognizing that research at Amundsen-Scott South Pole Station would continue beyond the life of the station and that facility needs were increasing, the National Science Foundation and the U.S. Naval Support Force Antarctica began planning a replacement station. NCEL assisted with research and development for this project.

Construction began during the 1970-1971 austral summer and was completed during the 1974-1975 austral summer. The design guidelines for this station specified a 10-year usable life rather than a permanent station that might unnecessarily restrict the science program. When the usable station life had passed, new requirements would determine the kind of station to be constructed. Because the design of this station was more successful than anticipated, the station has been in service for 13 years, 3 years longer than its planned usable life.

Beyond its location and a few special structures, the station is similar to many science support facilities in the United

States. Like these facilities, South Pole Station provides food and lodging, has space for instruments, and is maintained by work crews. The significant difference between the antarctic station and a facility in the United States is the hazard associated with support equipment that breaks down.

Assessing station life

In considering the usable life of a station, engineers at NCEL apply basic facility management principles, while keeping in mind such variables as the need for reliable life support equipment. Safety, cost, and required operational capability, universally important in facility management, can be broken down into five factors:

- structural safety
- operational safety
- science program requirements

- habitability standards
- annual costs

Evaluation of the current and projected condition of these five factors will indicate the appropriate date for closing an existing station and opening the next one. Although NCEL is studying only the structural safety of the station dome, in the discussion below South Pole Station is used as an example of how these five factors can be applied.

Structural safety

A safe structure is mandatory for continued use of an existing station. If the structure becomes unsafe or if significant structural safety problems are predicted, these conditions must be rectified immediately and may necessitate scheduling construction of a replacement.

South Pole Station is composed of a dome and archways. To analyze the current and predicted condition of the

dome, foundation settlement and snow, wind, and operational loads are applied to a finite element model of the dome structure. Predicted conditions of these variables are also imposed on the model. The results from this analysis are compared to accepted safe allowable stresses for aluminum structures. This comparison enables NCEL engineers to assess present and future structural safety of the dome.

The archways are also exposed to differential, snow, and operational loading. Practical experience from other antarctic stations with archways exposed to similar or more severe conditions indicate stress and structural stability are not a problem now and will not be in the near future.

Operational safety

Safe operational conditions also are mandatory for continued use of a station, and efforts to measure operational safety should be ongoing. The costs of maintaining operational safety are charged to continuing operations and maintenance expenses. Review of fire regulations, testing of response times of damage-control teams, and inspection of back up life support equipment are only a few of the necessary safety considerations. Often overlooked issues include the availability of unusual spare parts that are not needed regularly or of staff with special skills to cope with unexpected events.

Science program requirements

South Pole Station exists to support antarctic research. As the research program evolves, the methods used by researchers to study various subjects also evolve, and different facility support requirements may develop. This may mean, for example, as radio transmission becomes more important, additional electrical generating capacity has to be incorporated into the power plant. More importantly, the growth of the science program may dictate larger station populations.

At specific intervals, current and future facility needs of the South Pole scientific community should be compared with current and potential facility capabilities. If the facility's capability to support science requirements and the stated needs of the community diverge significantly, several questions must be answered. One question is whether these additional needs can be met economically by modification or new construction. If new construction is the most economical way to provide additional fa-

cility capability, then replacing the existing station is desirable.

Habitability standards

A certain level of habitability, which includes berthing, food services, and work spaces, is provided to South Pole Station occupants. The adequacy of this support depends principally upon the size of the station population at any given moment.

Generally, facilities are designed and managed based on appropriate standards of habitability. Decisions about facility management are made by comparing existing habitability with accepted standards. For example, the decision to build additional berthing would be based upon the number of people sharing the existing berthing space. Comparison of existing conditions with accepted standards indicates whether building the addition is needed.

Habitability standards have been developed for McMurdo Station and could be developed for South Pole Station. The standards incorporated into the original design specification for the present South Pole Station were based on a station population of 24. However, during the 1985-1986 austral summer, the station population frequently exceeded 85 people. It can be argued that a de facto standard exists for South Pole Station because even with the increased station population the station continues to be used. However, this de facto standard has not been measured or documented.

To determine if the existing standard is acceptable, the following approach could be used.

- Establish what habitability standards are appropriate for South Pole Station.
- Determine what level of habitability is provided by the existing station at current and projected population levels.

• Compare established appropriate standards with de facto habitability conditions existing at the station.

Coherence with or short-falls from established standards will indicate a level of construction to recover station habitability.

Annual maintenance costs

An ideal facility provides the required operational capacity at minimum cost. Unfortunately, minimum costs are rarely achieved, and capacity is always some margin larger or smaller than the required amount. South Pole Station exhibits both these conditions.

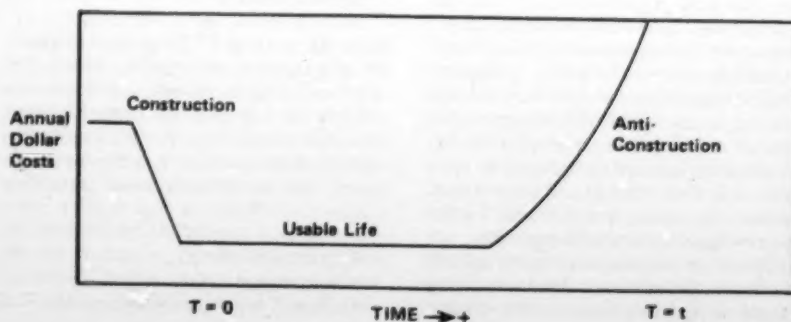
Facilities have three distinct phases in terms of costs: construction, usable life, and accelerating deterioration. These three phases are illustrated in the graph in figure 1.

Figure 1 shows the three phases of the annual costs of a facility. Construction involves purchase of materials, labor expenses for workers, and coordination. All of these occur while the existing facility is still in use. Because of these large expenditures, annual costs are high during the construction phase. $T \geq 0$ defines the point when a facility is available for use. Construction occurs before the facility is available for use, or when T is less than 0.

Usable life starts at $T \geq 0$, and relatively constant annual costs exist. $T > t$ concludes the usable life and is characterized by accelerating deterioration of the facility. This accelerating deterioration continually increases annual costs, as shown in the right-hand side of figure 1.

Integrating the function shown in figure 1 with time, the total cost of a facility can be derived. Figure 2 illustrates this and an important concept regarding total costs throughout the life cycle of the

Figure 1. Time versus annual facility cost; three phases.



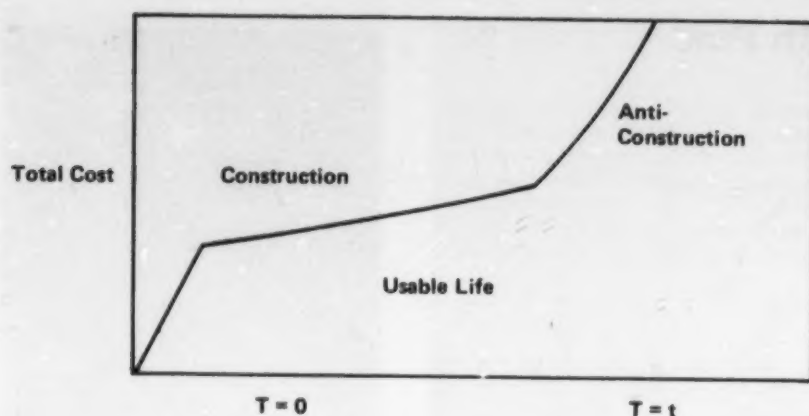


Figure 2. Total facility cost in respect to time.

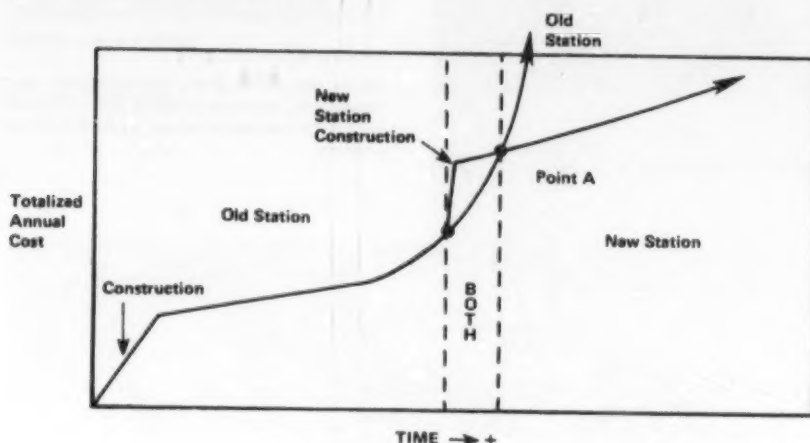


Figure 3. Existing and replacement station cost trade-offs.

facility. Usable life costs contribute only a fraction of the total facility life cycle cost. Besides construction costs, which are fixed by required capacity, the largest and most variable cost is increased maintenance during accelerating deterioration. Maintenance costs are important when deciding the appropriate time to replace a facility. If accumulated costs increase more quickly in accelerating deterioration than usable life, then a point occurs when replacing the station is more economical than maintaining it. Figure 3 illustrates this concept.

At point A on the graph in figure 3 a new station is built. The cumulative cost of this new station is shown. Point a on this graph shows the cost of maintaining the existing station. Consequently, the graph demonstrates that maintaining a station during accelerating deterioration

can be more expensive than replacing the old station with a new one.

The graph also suggests how economics can be used to determine the optimum time to replace a station. However, using an economic analysis to determine optimal station replacement requires substantial information, particularly cost data throughout the station life. Costs of the proposed replacement station also are needed for this type of analysis. Because of long lead times for construction, most of this information has to be based on predictions derived from experience and is rarely as accurate as actual data. Finally, most of the necessary data for this analysis are frequently unavailable. To have this information, station designers would have to plan to obtain it from the facility opening.

Conclusion

Five factors (structural safety, operational safety, required operational capability, habitability standards, and annual costs) combine to determine the remaining usable life of South Pole Station. Preliminary results of NCEL's assessment of the dome structure indicate that no structural safety problem will develop before the other four areas contribute more significant problems. If the other four factors were analyzed, an optimal schedule for replacing South Pole Station could be determined.

—Gordon P. Hatcher, U.S. Naval Civil Engineering Laboratory, Port Hueneme, California 93043.

South Pole Station (elevation 2,835 meters) stands on top of 2,850 meters of moving ice. Because the ice sheet moves about 10 meters per year, U.S. Geological Survey personnel must relocate the marker for geographic pole each austral summer.

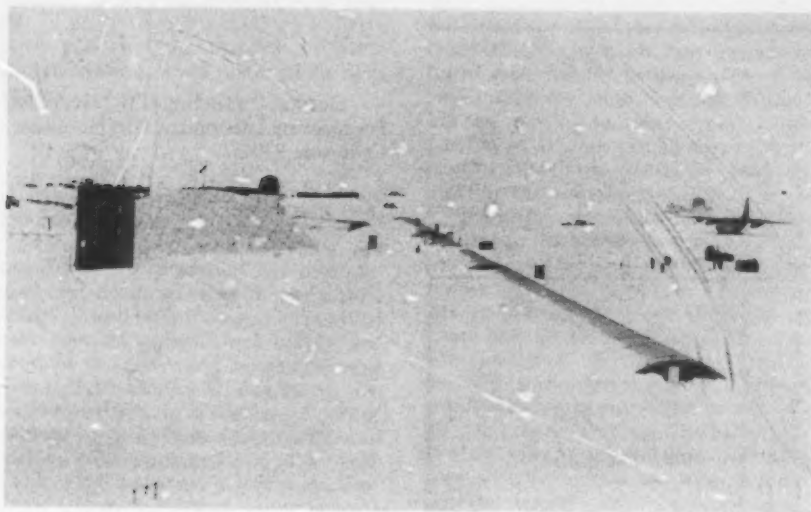
NSF photo by Ann Hawthorne.



Station life at the South Pole

About 1,300 kilometers (728 nautical miles) from McMurdo Station, the geodesic dome of Amundsen-Scott South Pole Station breaks the nearly featureless horizon of East Antarctica's polar plateau. Each austral summer more than 50 people come to work and conduct re-

search; in the austral winter approximately 19 maintain the station and continue year-round research. The previous article discussed the structure and safety of the station. The following pages pictorially describe life and research at the South Pole during the austral summer.



NSF photo by Ann Hawthorne.

The station dome is 50 meters wide and 16 meters high. Along with steel archways, 14 meters by 24 meters, the dome covers modular buildings, fuel bladders, and equipment. Two buildings—"skylab" (left of dome) and the weather balloon inflation tower (center right, behind station)—complete the main station complex. Removed from the main station is the clean air laboratory, which is used to monitor carbon dioxide, chlorofluorocarbons, and other constituents of the atmosphere.

NSF photo by Ann Hawthorne.



NSF photo by Ann Hawthorne.

Inside the dome three prefabricated vans house living quarters, a galley, a science center, a communications center, a post office, and a library.



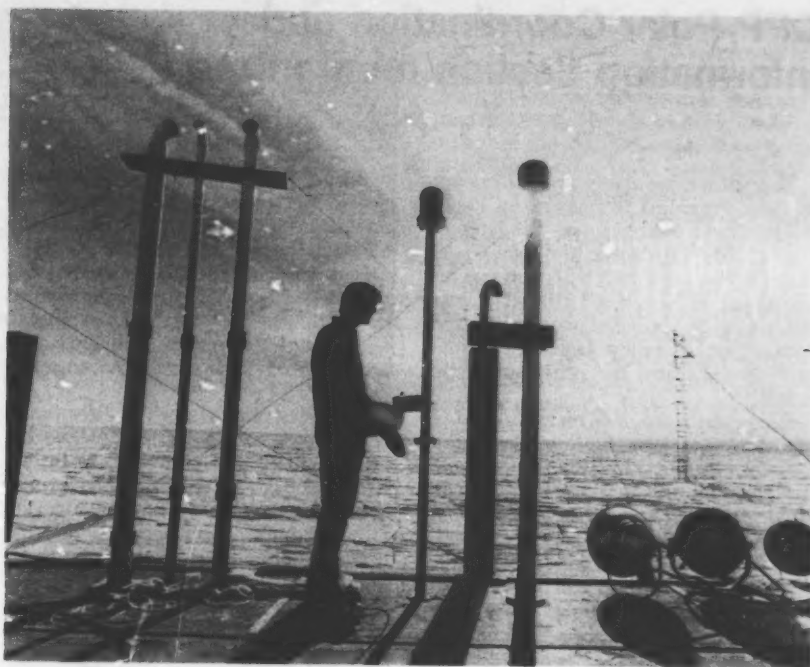
Although the South Pole receives only trace amounts of snow, drifting snow has accumulated around the dome and arches so that the complex is now below the snow surface. Each austral summer large tracked vehicles (left) "landscape" the snow around the dome to help prevent damage to the structure. Snow is also collected in this way to fill the melter that provides water for the station.

The South Pole provides a unique combination of geomagnetic, geographic, and climatic conditions for research. Among these are continuous daylight during the austral summer, high altitude, low humidity, and isolation from pollution producing sites. Research includes glaciology, geophysics, meteorology, upper atmosphere physics, meteorology, astronomy, and biomedical studies. Some examples follow.



NSF photo by Ann Hawthorne.

Ice cores (glaciology).



NSF photo by Ann Hawthorne.

Monitoring of atmospheric constituents (lower atmosphere studies).



NSF photo by Ann Hawthorne.

Solar telescope (astronomy).

An automated geophysical observatory, used to obtain ground-based observations of magnetospheric and ionospheric phenomena (upper atmosphere physics).

NSF photo by Ann Hawthorne.



DPP Polar Coordination and Information Section reorganized

To improve the ability of the Division of Polar Programs to respond to Presidential and Congressional mandates in the Arctic and Antarctic, the Polar Coordination and Information Section was reorganized in November 1986. The section is now composed of two groups, one focusing on antarctic policy and information projects and the other on arctic policy.

Succeeding Joseph Bennett as head of the section is John B. Talmadge, who joined the division in 1985 to coordinate the Foundation's activities under the Arctic Research and Policy Act of 1984. Anton Inderbitzen, who was DPP's associate chief scientist, is head of the antarctic staff. This group will be responsible for gathering, compiling, and analyzing information about U.S. and foreign activities in Antarctica, improving inter-

agency and international coordination of antarctic programs, managing specimen and data collections, developing and defending the public's interest in interagency and international forums, and administering U.S. laws and regulations in Antarctica. They also will continue to be responsible for the division's antarctic-related publications and an information program.

The arctic staff under the direction of Jerry Brown will lead government-wide coordination and communication activities with emphasis on implementing the arctic 5-year plan. They will focus on an arctic information network, international cooperation, U.S. arctic research logistics capabilities, and coordination of Greenland research. Dr. Brown came to DPP from the U.S. Army's Cold Regions Research and Engineering Laboratory in 1985.

Currents, water quality, bottom sediments, and bathymetry in McMurdo Sound near McMurdo Station

At the request of ITT/Antarctic Services Inc., Raytheon Service Company performed a water quality study in McMurdo Sound in November and December 1982. We were evaluating potential locations for the seawater intake for a replacement desalination unit, which was installed at McMurdo Station. In this article we present data on currents, water quality, bottom sediments, and bathymetry, which may be of interest to researchers conducting projects in McMurdo Sound adjacent to the station.

Figure 1 shows where we collected samples and took measurements. We monitored currents from 24 November to 23 December 1982 at five locations identified by depth. We deployed Endeco Model 105 current meters at mid-depth on moorings suspended from tri-

pods erected over holes in the sea ice. Bottom pressure was monitored at the 14-meter station with an Aanderaa WLR-5 gage. During this period, water samples were collected with 2 liter Kemmerer bottles, and bottom sediments were sampled with a 0.003 cubic-meter Ponar grab at the stations shown in figure 1. Water depth was measured with an Elac LAZ 100 depth sounder through holes drilled in the ice at 55 locations distributed throughout the study area.

The diurnal tide in McMurdo Sound strongly influences currents. The tidal range, which averaged 0.8 meters during the 29 days that we recorded, exhibited a marked variation in range over a 13-day cycle. The spring range was 1.1 to 1.5 meters, whereas the neap range was 0.2 to 0.7 meters. The results, shown

Two men die after fall into crevasse

Two employees of ITT/Antarctic Services, Inc. (ITT/ANS), the National Science Foundation antarctic support contractor, were killed on 23 November 1986 while hiking about 2 mile northeast of McMurdo Station. Along with another ITT/ANS employee, Thomas J. Powell, the two men, Matthew M. Kaz, 25, of San Carlos, California, and John E. Smith, 44, of Portland, Oregon, were returning to McMurdo Station from Castle Rock, an outcrop about 3 miles from the station. They had deviated from the flagged route to go to nearby Scott Base, the New Zealand station on Ross Island.

The two victims fell approximately 70 feet into the crevasse. The third man, Thomas Powell, went to McMurdo Station to get help, and a rescue team was dispatched to the site immediately. The men were extracted from the crevasse but were unconscious when they reached the surface. They were taken to the medical facility at McMurdo Station where they were pronounced dead. Their bodies were flown to Christchurch, New Zealand, and onward to their hometowns in the United States. Their deaths has prompted the National Science Foundation to establish a special committee to review safety procedures in Antarctica.

These two fatalities are the first to occur in the U.S. Antarctic Program since February 1982, when a Navy enlisted man was killed while assisting in unloading USNS *Southern Cross*, the annual supply ship. Since 1946, 49 Americans (including these two men) have died in Antarctica while participating in the U.S. Antarctic Program.

in figure 2, are similar to previous tide measurements taken in this area by MacDonald and Burrows (1959) and by Heath (1971). Their analyses indicate that the range variations result from interaction of the K₁ (luni-solar) and O₁ (principal lunar) declinational components which have periods of 23.93 hours and 26.87 hours, respectively, and cause a 360° phase shift every 13 days.

Currents recorded during the study exhibited two speed maxima every 25 hours, one peak corresponding to tidal flood and the other to tidal ebb. The tide floods in a southeasterly direction and ebbs toward the west and northwest. Depending on the location, either the flood or ebb predominated in terms of flow speed and duration. Maximum current speeds ranged from 15 to 30 centimeters

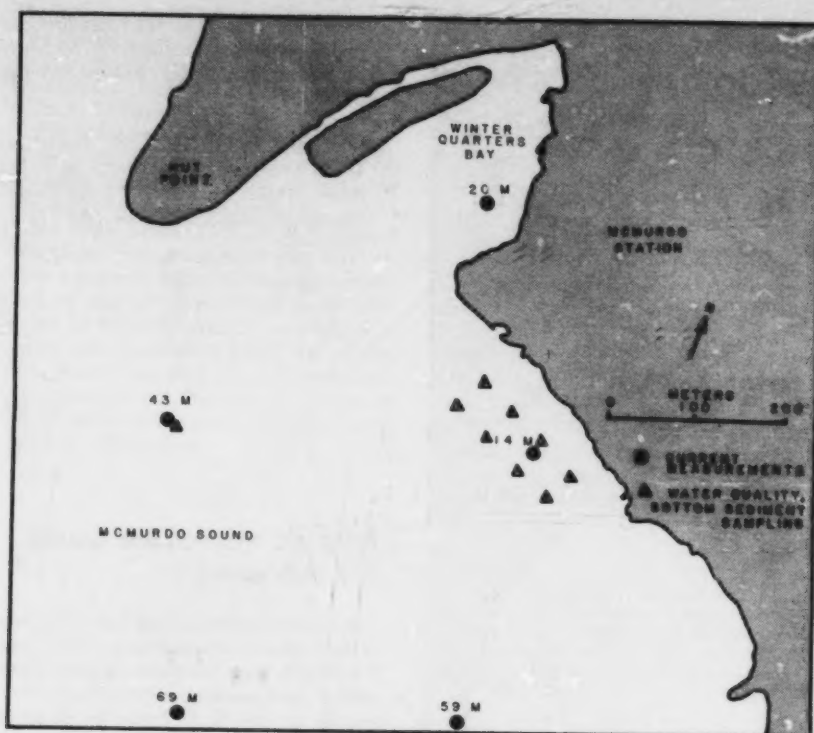


Figure 1. Field measurement and sampling stations.

per second at the deeper measurement stations and 10 to 15 centimeters per second adjacent to shore. In Winter Quarters Bay, current speeds were so minimal (0 to 3 centimeters per second), that conditions could be described as nearly stagnant. Figure 2 shows current speeds and directions recorded at the 69-meter station.

Inequalities between flood and ebb flow resulted in net non-tidal transports. These transports, calculated for each measurement location, were 120 to 160 meters per day at the deeper stations, 20 to 30 meters per day near shore, and 7 to 14 meters per day in Winter Quarters Bay. Note that these distances are roughly one order of magnitude less than the associated flood and ebb tidal excursions. Net transport vectors averaged over the 29 days of our study are shown in figure 3. The orientations of the vectors suggest the existence of a counterclockwise gyre off the coast near McMurdo Station.

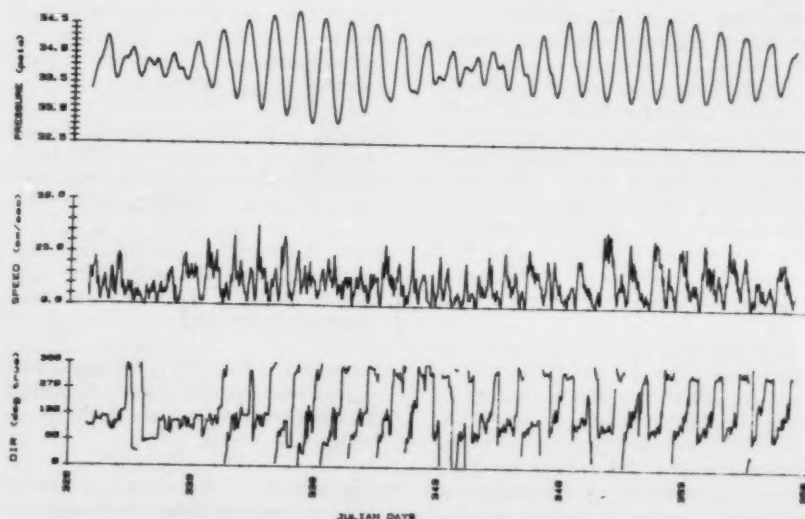
These results reinforce those of earlier studies of currents in McMurdo Sound with respect to the diurnal tidal influence and spatial variability. The net transport directions support the hypotheses proposed by Gilmour (1975), Hodgson (1907), Dayton and Oliver (1977), and Hodson and others (1981) that there is a southerly flow along the southwestern side of Ross Island.

Water samples were collected at different tidal stages and at various locations in the water column. We analyzed these samples for the following constituents:

fecal coliforms, ammonia, hydrogen sulfide, cyanide, PCB's, trace metals (arsenic, barium, cadmium, chromium, lead, selenium, silver, and mercury), and suspended solids. Concentrations of many of these constituents were below detectable limits. Those constituents detected in measurable quantities, and their average concentrations among all samples, included: fecal coliforms (85 col per 100 milliliters); ammonia (0.35 milligrams per liter); hydrogen sulfide (0.35 milligrams per liter); cadmium (0.06 milligrams per liter); chromium (0.07 milligrams per liter); lead (0.05 milligrams per liter), and suspended solids (6.6 milligrams per liter). These results indicate that the discharge of sewage and other waste disposal practices have affected water quality adjacent to McMurdo Station.

Bottom sediments were sufficiently compact to resist penetration by gravity corer, and samples were collected with a grab. All samples consisted of a heterogeneous mixture of gravel, sand, silt, and clay. Sand was the dominant grain size, exceeding 50 percent by weight in all samples; silts and clay-size particles comprised less than 10 percent. The sand fraction was predominantly volcanic glass, quartz at the nearshore stations and biogenic (sponge spicules, skeletal fragments) at the 43-meter station. Most of the nearshore samples contained small quantities of anthropogenic particles (wood, plastic, paper, paint chips, fibers, etc). At the stations sampled, there was no physical evidence for a layer of sludge, previously

Figure 2. Bottom pressure (14-meter station) and current speed and direction (69-meter station) recorded from 24 November to 23 December (Julian days 328-357) 1982.



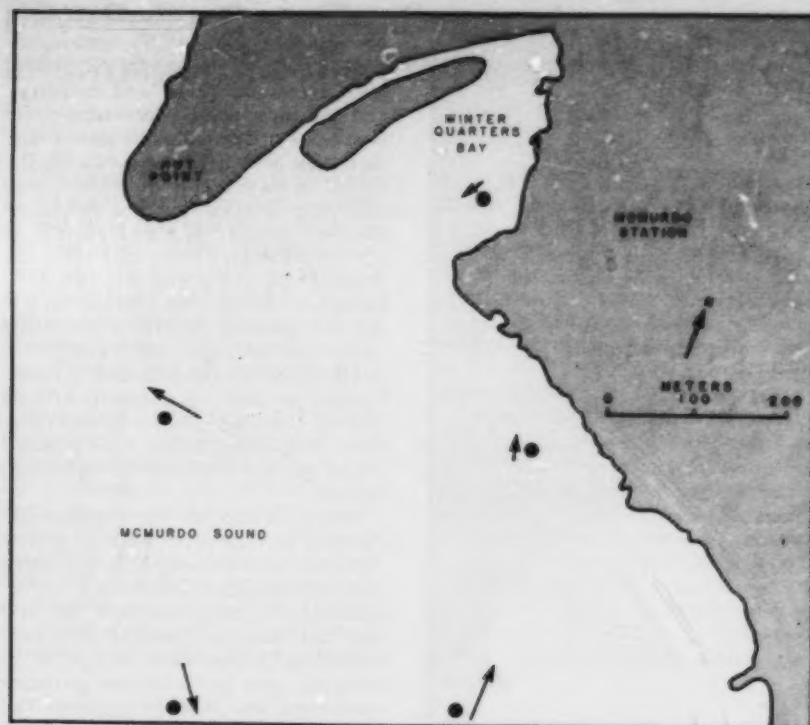


Figure 3. Relative net current transport vectors, 24 November to 23 December 1982.

reported by divers, resulting from discharged sewage.

Trace metal contents in bottom sediments, in milligrams per kilogram dry weight (DW) averaged for all samples, were: As—17, Ba—188, Cd—1.9, Cr—70, Pb—86, Hg—0.4, Ag—0.7. Both oil/grease (1788 milligrams per kilogram DW) and PCB's (73 milligrams per kilogram) were detected in the samples; cyanide was absent. The average hydrogen sulfide and total volatile solids contents were 6.4 milligrams of sulfur per kilograms dry weight and 21 milligrams per gram respectively. Natural background levels of radionuclides were present in the sediments collected at all stations. Hydrogen sulfide, oil/grease, As, Pb, Hg, Cd, and Ag were enriched at the inshore stations in comparison to the 43 meter station. Contributing factors appear to be the discharge of sewage inshore and differing mineralogy.

Our Raytheon Service Company report ("Report on the McMurdo Station water quality study," Raytheon Service Company, 1983, available through ITT/Antarctic Services) provides the bathymetric data and a more complete accounting of study methodology and results.

—Charles V. Beckers, David O. Cook, Marian J. Falla, Gary C. Parker, and Martin J. Speranza. Raytheon Service Company, Hammarlund Way, Middletown, Rhode Island 02840.

References

- Dayton, P.K., and J.S. Oliver. 1977. Antarctic soft-bottom benthos in oligotrophic and eutrophic environments. *Science*, 197, 55-58.
- Gilmour, A.E. 1975. McMurdo Sound hydrological observations, 1972-1973. *New Zealand Journal of Marine and Freshwater Research*, 9, 75-95.
- Heath, R.A. 1971. Tidal constants for McMurdo Sound, Antarctica. *New Zealand Journal of Marine and Freshwater Research*, 5, 376-380.
- Hodgson, T.V. 1907. On collecting in antarctica seas. *Natural History Report of the National Antarctica Expedition 1901-1904*, 3, 1-10.
- Hodson, R.E., F. Azam, A.F. Carlucci, J.A. Fuhrman, D.M. Karl, and O. Holm-Hansen. 1981. Microbial uptake of dissolved organic matter in McMurdo Sound, Antarctica. *Marine Biology*, 61, 89-94.
- MacDonald, W.J.P., and A.L. Burrows. 1959. Sea-level recordings at Scott Base, Antarctica, 1957. *New Zealand Journal of Geology and Geophysics*, 2, 297-314.

Tectonic map of the Scotia Arc published

Recently, the first colored tectonic map of the Scotia Arc region was published by the British Antarctic Survey (BAS). Preparation and publication were supported jointly by the U.S. National Science Foundation's Division of Polar Programs, through grant DPP 87-20629 to I.W.D. Dalziel, and by the BAS Natural Environment Research Council.

The 1:3,000,000-scale map illustrates the tectonic history of the Scotia Arc region, an area between 50°S to 73°S and 25°W to 80°W that covers the Antarctic Peninsula, South Orkney, South Falkland, South Sandwich, and South Georgia islands, and the southernmost part of South America. The map provides the latest synthesis of the bathymetry of the region and terrestrial and marine geology and geophysics, including shallow and deep earthquake epicenters and focal mechanisms, magnetic anomalies, the location of dredging stations, and Deep Sea Drilling Project drillhole sites. Brief descriptions of tectono-stratigraphic units, which are used to illustrate the geology of the area, are given in the legend, along with a chart that compares the geologic evolution of South America, the Falkland Island and South Georgia to the Antarctic Peninsula and the South Shetland and South Orkney islands. The legend also includes a list of references.

Marine geophysical and seismic data for the map were compiled by P. F. Barker and colleagues at the University of Birmingham in the United Kingdom; terrestrial geologic data were compiled by I.W.D. Dalziel Lamont-Doherty Geological Observatory of Columbia University* and by B.C. Storey and M.R.A.

*I.W.D. Dalziel is now at the Institute for Geophysics, University of Texas at Austin.

Flat or folded copies of the *Tectonic map of the Scotia Arc*, published as Sheet BAS (Misc) 3, Edition 1 (1985), are available through Edward Stanford Ltd., 12-14 Long Acre, London WC2E 9LP, United Kingdom. U.S. purchasers may send either a money order for 10 pounds sterling or may provide a bank credit card (Visa or Master Charge) number. If a credit card number is used, the expiration date of the card must be included. The price in U.S. currency is \$15 plus a \$4.50 surcharge to cover bank charges if paid in U.S. dollars.

From 8 to 18 November 1981 we participated in cooperative research, sponsored by the U.S. National Science Foundation (NSF) and by Argentina's Centro Austral de Investigaciones Científicas (CADIC), aboard the NSF research ship *Hero** (Cruise 81-5). With the support of *Hero*, we were able to study the Peninsula Mitre of extreme eastern Tierra del Fuego and Isla de los Estados, areas that scientists cannot reach easily.

^aHere, the wooden, ice-strengthened research ship owned by the National Science Foundation, operated in Antarctic and South American waters between 1968 and 1984. The ship is now owned by Reedsport, Oregon, and is used as a museum.

During the 10-day cruise, we surveyed 33 beaches in 19 different bays and coves (figure 1) and checked others with binoculars from a Zodiac when sea conditions prevented landings on shore. Two days of shore time were lost due to lack of suitable beaches or to high winds. Because of gales, we could not survey the north coast of Peninsula Mitre, although

[illegible]



Figure 2. Taking notes on pilot whale skulls aboard R/V *Hero*.

one exceptional day permitted us to check all but three beaches on the south side of Isla de los Estados.

We collected 38 cetacean and 6 pinniped specimens. They were identified by comparison with the Goodall collection in Ushuaia and are deposited in that collection and at the local Territorial Museum.

Strandings

Mystecetes. We found scattered vertebrae of large whales on nearly all beaches, but most could not be identified and were not collected.

Balaenoptera borealis: In the eastern Beagle Channel a complete skull of an animal stranded in April 1980 was recovered and earbones from two specimens stranded in 1964 were taken. Cervical vertebrae were found at Bahia Aguirre.

Eubalaena australis: We photographed a skull at Bahia Valentin, but could not collect it due to its large size and worn state.

Odontocetes.

Mesoplodon hectori: Several vertebrae were found at Bahia Valentin.

Ziphius cavirostris: At Bahia Buen Suceso, we found a cranium and several vertebrae of a very young animal. In addition, unidentified ziphiid vertebrae were found at Caleta San Mauricio.

Hyperoodon planifrons sp: A worn cranium which is unlike known specimens of this species was found buried in the sand at Caleta Llanos on Isla de los Estados.

Orcinus orca: We found a mandible and several vertebrae at Bahia Colnett.

Globicephala melaena: At Bahia Sloggett and Caleta Brent, we found single crania. While at Caleta San Mauricio, Peninsula Mitre, we retrieved 22 crania and 2 mandibles that represented a mass stranding. Eight of these crania showed evidence of unusual bone erosion in the preauricular region, indicating disease throughout the family group. During subsequent expeditions, nine more crania were found.

Gale force winds prevented us from disembarking on the beach of southern Bahia Flinders, Isla de los Estados, where Goodall found nine recently dead pilot whales in November 1971 during *Hero* cruise 71-5.

No remains of pilot whales were found at Puerto Roca, where Angle and Bridge collected a skull from one of two badly

decomposed animals found in May 1971 (Pine, Angle, and Bridge 1978).

Lagenorhynchus australis: A beach-worn cranium and deformed vertebrae were found at Bahia Valentin.

Lissodelphis peronii: We encountered only three vertebrae at Puerto Cook, Isla de los Estados. One skull of this species was collected by Goodall and two by A. Goztonyi at Bahia Thetis during a botanical expedition in November 1969 (Brownell, 1974; Goodall, 1978b).

Sightings

Peale's dolphins (*Lagenorhynchus australis*) followed our Zodiacs on seven occasions in Bahias Sloggett and Moat. Brief sightings of dolphins, most probably this species, were made off Bahias Capitan Canepa and Blossom, Isla de los Estados.

Other mammals

Although this was a cetacean expedition, we also made notes and collected a few specimens of other mammals.

Hydrurga leptonyx: A complete leopard seal skeleton was collected at Bahia Aguirre.

Mirounga leonina: One southern elephant seal skull was collected at Caleta Brent on Isla de los Estados. Although elephant seals are fairly common in Fuegian waters, we did not see any during this cruise.

Arctocephalus australis: One skull was collected at Bahia Valentin. We observed fur seals in Bahia Capitan Canepa, where they had been seen in May 1971 (Pine et al., 1978).

Otaria flavescens: Crania of southern sea lions, the most common pinniped in Fuegian waters, were seen at most localities and were collected at Bahia Valentin and Puerto Roca. We saw sea lions at Bahia Capitan Canepa and several other localities during the 1971 and 1981 expeditions. At Bahia Thetis, where a sealing factory operated in the 1940's, right mandibles of seals were collected for future aging studies.

Although Bridge and Angle sighted otters *Lutra provocax* at Puerto Celular and Bahia York and saw tracks at Puerto Roca (Pine et al., 1978), and Chebez (1983) saw tracks at Bahia San Antonio, we saw none. Goodall saw otter runs on the peninsula at the mouth of Puerto Basil Hall in 1971.

Guanacos *Lama guanicoa* are common all over the Isla Grande de Tierra del Fuego and especially so on the Peninsula Mitre where their main enemy (man) seldom goes. We saw animals at Bahias Sloggett, Buen Suceso, Thetis, and Caleta San Mauricio. No sightings on Isla de Los Estados have been recorded.

Summary

Little research has been done on the small cetaceans of the extreme eastern part of Tierra del Fuego (Brownell 1974; Pine et al 1978). During this brief expedition, we were able to identify the best beaches for cetacean remains both on the Peninsula Mitre and Isla de los Estados and to outline areas for future work. Through our stranding and sighting programs, carried out in Tierra del Fuego since 1976 (Goodall, 1978a, b; Mermoz and Goodall, 1980; Goodall, 1985; and others), we have found that at least 20 species of smaller cetaceans and 7 species of large whales either strand on or are sighted near Tierra del Fuego. During cruise 81-5 we found six species of smaller cetaceans (30 percent) of those now known to be present) and at least two of the large whales (29 percent). The finding of a mass stranding of pilot whales will enable us to compare this family grouping with others on Tierra del Fuego and from other areas of the world.

We greatly appreciate the competent work of Captain Pieter J. Lenie and his crew in very stormy waters, especially Zodiac drivers Bill Fitz and Harrison Huster, who efficiently took us to remote sites that were nearly inaccessible. The National Science Foundation provided support by making space available to our science party on the research ship *Hero*. Cetacean studies and surveys in Tierra del Fuego, supported by the National Geographic Society since 1977 and by CADIC since 1981, provide data for evaluating and understanding the behavior and distribution of marine mammals in the southern ocean region. They also contribute to the data base needed for managing antarctic marine living resources.

—R.N.P. Goodall and A.R. Galeazzi, Centro Austral de Investigaciones Científicas (CADIC), 9410 Ushuaia, Tierra del Fuego, Argentina.

References

- Brownell, R.L., Jr. 1974. Small odontocetes of the Antarctic. In V.C. Bushnell (ed.) *Antarctic Mammals*, Antarctic Map Folio Series, Folio 18. New York, New York: American Geographical Society.
- Chebez, J.C. 1983. Isla de los Estados. *Vida Silvestre*, 2 (8): 10-16.
- Goodall, R.N.P. 1969. *Tierra del Fuego*. Buenos Aires, Argentina: Ediciones Shanamaian.



Figure 3. Cranium of sei whale before loading on Zodiac.

- Goodall, R.N.P. 1978a. *Tierra del Fuego* 1979. (Third Edition). Buenos Aires, Argentina: Ediciones Shanamaian.
- Goodall, R.N.P. 1987b. Report on the small cetaceans stranded on the coasts of Tierra del Fuego. *Scientific Reports of the Whales Research Institute* 30: 197-230.
- Goodall, R.N.P. 1985. Argentina: progress report on cetacean research, 1979-1984. *Reports of the International Whaling Commission*, 35: 155-158.
- Mermoz, J.F., and R.N.P., Goodall. 1980. Argentina: Progress report on cetacean research, 1975-1979. *Reports on the International Whaling Commission*, 30: 139-141.
- Pine, R.H., J.P. Angle, and D. Bridge. 1978. Mammals from the sea, mainland and islands at the southern tip of South America. *Mammalia*, 42 (1): 105-114.

Volume 14, Antarctic Bibliography available

During 1986 the Cold Regions Bibliography Project of the Library of Congress Science and Technology Division

completed Volume 14 of the *Antarctic Bibliography*. This volume, part of a continuing series of compilations and abstracts of antarctic literature published since 1951, is sold by the Government Printing Office. The National Science Foundation has provided support to the Library of Congress for this project since 1963 as part of the Polar Information Program.

Containing 2,794 abstracts of the world's antarctic literature, Volume 14 was compiled during 18 months that ended in June 1985. Fully indexed, the 604-page, hardbound volume includes abstracts distributed in issues 137 through 154 of *Current Antarctic Literature*, a monthly bulletin compiled by the Library of Congress and available to qualified scientists and institutions through the Polar Information Program. A computerized data base is used to generate the bulletins, the bibliographies, and cumulative indexes. The base can be queried on line as the COLD data base in SDC's Orbit bibliographic retrieval system.

The book is arranged in 13 subject categories: general; biological sciences; cartography; expeditions; geological sciences; ice and snow; logistics, equipment, and supplies; medical sciences; meteorology; oceanography; atmospheric physics; terrestrial physics; and political geography. Abstracts that may fall into more than one category are listed in one section only and cross-refer-

enced at the end of the other pertinent sections. Four indexes are included—author, subject, geographic, and grantee. The author index includes coauthors and, for anonymous articles, the journal title. The geographic index contains names of stations, places, and geographic features as approved by the U.S. Board on Geographic Names. The grantee index provides the names of organizations and institutions that have received support from the National Science Foundation.

Abstracts are designed to be informative, and no attempt is made to verify or critically evaluate the author's statements or conclusions. For foreign-language articles, the title is given in English first with the original title following in brackets.

Volume 14 of the *Antarctic Bibliography* is available for \$26 from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. When ordering, please cite stock number 030-018-00025-7. Some earlier volumes are now out of print at the Government Printing Office but are still available in limited quantities from the Library of Congress to institutions wishing to complete a set. Inquiries for these volumes should be addressed to the Library of Congress, Science and Technology Division, Cold Regions Bibliography Project, Washington, D.C. 20540. An order blank for volume 14 may be obtained from the Polar Information Program, Division of Polar Programs, National Science Foundation, Washington, D.C. 20550 (telephone 202/357-7817).

Staff changes at DPP: departures and arrivals in 1986

Between 1 January and 31 December 1986, several staff changes occurred at the Division of Polar Programs.

Departures

After almost 34 years of service to the Federal government, *Kendall N. Moulton*, associate manager for the Polar Operations Section, retired on 31 December 1985. Mr. Moulton's career in polar science support began in 1951 when, as an employee of the U.S. Weather Bureau, he wintered at Donki Station in Thule, Greenland. He made his first trip to Antarctica in 1955 as part of the National

Academy of Sciences team for the International Geophysical Year (IGY) during which he served at McMurdo Station as U.S. Antarctic Program representative.

He came to the National Science Foundation in 1959 as a member of the Office of Antarctic Programs. During more than 25 years with the U.S. Antarctic program, Mr. Moulton held various positions, including associate program director, program manager for field operations, and associate manager of the Polar Operations Section. While on extended assignment in Antarctica he was often appointed Senior U.S. Representative in Antarctica.

In recognition of his contributions to the management of operations and logistics for the U.S. Antarctic Program, Mr. Moulton was presented NSF's Distinguished Service Award by Erich Bloch, Director of the National Science Foundation, during a ceremony in December 1985. The Distinguished Service Award is the highest honorary award that the Foundation grants to employees; it recognizes individuals who render singularly outstanding service within or beyond their required duties.

In January 1986, *Francis S.L. Williamson* resigned from the Division of Polar Programs (DPP) to become Director of the University of Alaska's Institute of Arctic Biology. Dr. Williamson, who joined the DPP staff as program manager for polar biology and medicine in 1978, had been Chief Scientist since November 1979. Before joining the National Science Foundation, he also served as commissioner of the Alaska Department of Health and Social Services and as director of the Chesapeake Bay Center for Environmental Studies of the Smithsonian Institution.

Walter Karver, U.S. Navy, completed a 4-year assignment as aviation projects manager for the Division of Polar Programs in February 1986. Commander Karver, who joined the DPP staff in September 1982, has been assigned to the USS *Nimitz* as head of the safety department. Before coming to work with the Foundation, he had served aboard the *Nimitz* as a pilot and maintenance officer.

In May 1986 the Division of Polar Programs bid farewell to *Walter R. Seelig*, international coordinator in DPP's Polar Coordination and Information Section. After a 44-year career in the Federal service, Mr. Seelig retired. After graduating from Brooklyn College in 1941, he began his government career when he joined the U.S. Geological Survey (USGS) in 1942. From 1958 to 1960 he was on the USGS planning staff. During this time he was special assistant to the Chief Topographic Engineer for Antarctica.

Mr. Seelig made his first trip to Antarctica in 1959. Shortly after this he came to the National Science Foundation for a 9-month assignment and remained with NSF until he retired in May 1986. During the last 26 years, Mr. Seelig has served in a variety of positions related to the U.S. Antarctic Program, including geodetic liaison officer, associate program director for the international cooperation and information program, and international coordinator. From 1976 until 1986 he was the U.S. Antarctic Program representative in Christchurch, New Zealand, during the austral summer. For his contribution to the U.S. Antarctic Program, Mr. Seelig received NSF's Meritorious Service Award. This award, the second highest granted to Foundation employees, recognizes individuals who render meritorious service within or beyond their required duties.

In October 1986, *Joseph E. Bennett*, head of the Polar Coordination and Information Section, retired from Federal service. Before joining the NSF's Division of Polar Programs in 1976, Mr. Bennett had been in charge of special projects in the ocean science and technology division of the Office of Naval Research (ONR). While at ONR, he managed the development of a shipboard navigation system for the University-National Oceanographic Laboratory System and was project officer for development of an unmanned arctic research submersible under contract to the University of Washington. A graduate of the U.S. Naval Academy, he also held a master's degree in geodetic science from Ohio State University. For his contribution to U.S. policy in Antarctica, Mr. Bennett received the National Science Foundation's second-highest honorary recognition, the Meritorious Service Award.

Arrivals

In February 1986 *Arthur L. Kilpatrick*, U.S. Navy, succeeded Commander *Walter Karver* as aviation projects manager in DPP's Polar Operations Section. Commander Kilpatrick previously was the executive officer at the Naval Station, Annapolis, Maryland. He has also served in the Pentagon office that is responsible for Naval aviation manpower and was the Commanding Officer of Training Squadron Twenty-seven in Corpus Christi, Texas. As a Navy aviator, he has flown 5,000 hours and made 500 carrier landings in jet and propeller airplanes.

Ted E. DeLaca joined the staff as head of the Polar Science Section in July 1986 for a 2-year assignment at the National Science Foundation. A marine biologist, Dr. DeLaca has been an assistant research biologist at Scripps Institution of

Oceanography in La Jolla, California. He received his bachelors degree in aquatic microbiology in 1969 and his doctorate in marine microbial ecology in 1976 from the University of California at Davis. Dr. DeLaca, who succeeds Francis S.L. Williamson, has conducted research in the Ross Island and Antarctic Peninsula regions since 1971.

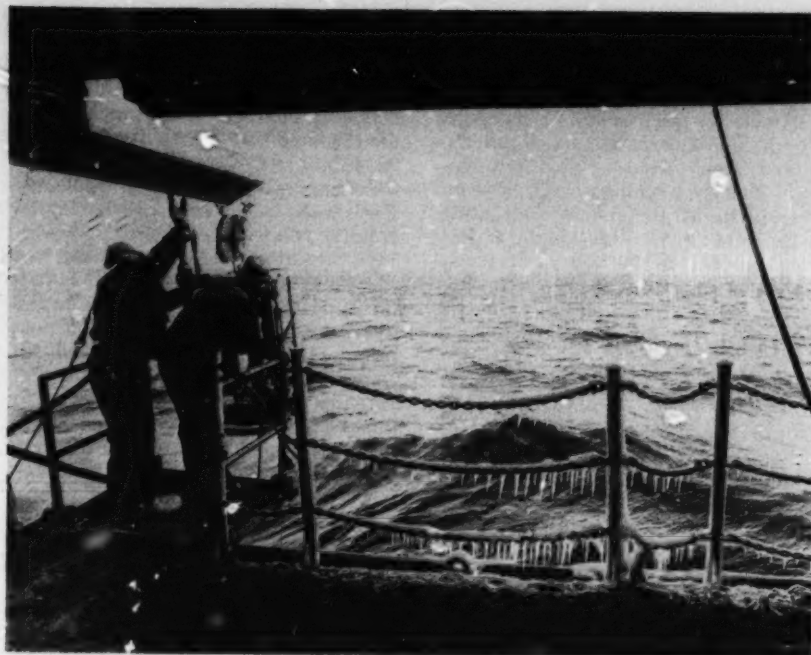
In August 1986, Craig S. Lingle joined the polar science section as program manager for glaciology. Dr. Lingle, who fills the position that has been vacant since 1985, was previously a research associate at the Cooperative Institute for Research in the Environmental Sciences, University of Colorado. He received his doctorate in geophysics, mathematics, mechanics, and geology from the University of Wisconsin.

Herman R. Zimmerman came to the division in September 1986 as program manager for earth sciences. Prior to joining the division, Dr. Zimmerman was a professor and chairman of the Department of Geology at Union College in New York state. He holds a Ph.D. in geology and oceanography from the University of Rhode Island.

Although as announced above Kendall Moulton retired in 1985, he returned to the U.S. Antarctic Program in October 1986 to serve as NSF Representative New Zealand, the position previously held by Walter Seelig. Mr. Moulton acted as the NSF representative in Christchurch during the 1986-1987 austral summer season.

Antarctic Research Series, Volume 43, published

Oceanology of the Antarctic Continental Shelf is devoted to the antarctic continental shelf because of the region's great depth and its climatic role in producing sea ice, ventilating the deep ocean, and wasting the antarctic ice sheet. In his preface editor Stanley S. Jacobs of Lamont-Doherty Geophysical Observatory defines oceanology as a "transitional stage between classical, discrete ship-board measurements and continuous remote sensing." Composed of 16 papers prepared by 32 scientists from 8 countries, the book is the first Antarctic Re-



NSF photo by Ann Hawthorne.

From the U.S. icebreaker *Polar Star* researchers lower instruments that will record temperature, salinity, and conductivity of sea water in the Ross Sea.

search Series volume that charts this transition from traditionally acquired oceanographic observations to continuous data collection by sophisticated technology.

The volume emphasizes the evolutionary process, which Dr. Jacobs describes in his introduction, not only by presenting literature reviews, early results from an ongoing experiment, and an updated description of some pioneering long-term current and temperature measurements but also by bringing together the work of oceanographers, geologists, geophysicists, and glaciologists. The papers are based on data obtained during austral summer cruises, time series measurements from bottom-moored instruments, and satellite imagery. By using geochemical tracers, high-resolution vertical-profiling instruments, and computer modeling the authors have been able to provide new insights into continental shelf circulation.

The book is accompanied by the GEB-CO circum-Antarctic chart, which portrays the continental shelf in relation to the glaciated continent and surrounding deep ocean. It displays several ephemeral bathymetric features and extensive areas that are relatively unknown.

The Antarctic Research Series, produced by the American Geophysical Union under a grant from the National

Science Foundation, is designed to serve scientists and graduate students actively engaged in antarctic or closely related

A oceanographer lowers buoys into the Ross Sea from the icebreaker *Polar Star*.

NSF photo by Ann Hawthorne.



research and others versed in the biological or physical sciences. It provides a continuing, authoritative medium for presentation of extensive and detailed scientific research results from Antarctica, particularly the results of the United States Antarctic Research Program, that are too long or otherwise inappropriate for the standard scientific journals. Much of the research that produced the data in this volume was conducted as part the U.S. Antarctic Research Program and supported by the National Science Foundation.

The hardbound, 312-page volume is available from the American Geophysical Union, 2000 Florida Avenue, N.W., Washington, D.C. 20009 (toll free telephone number; 800/424-2488) for \$39.

Obituaries

Paul C. Daniels

On Sunday, 6 April 1986, at the Memorial Sloan-Kettering Cancer Center in New York City, former Ambassador Paul C. Daniels died of a heart attack after surgery for cancer of the tongue. Ambassador Daniels, a former U.S. State Department Special Advisor on Antarctica, was a leading American figure in the formulation of the Antarctic Treaty. A memorial service was to be held in Lakeville, Connecticut, in June 1986 after the funeral.

Born in 1903 in Buffalo, New York, Ambassador Daniels graduated from Yale University in 1924. He did postgraduate work in France at universities in Dijon, Grenoble, and Toulouse. After teaching French briefly, he joined the foreign service and held diplomatic and consular posts in Colombia, Brazil, Honduras, and Ecuador. He was ambassador to Honduras in 1947 and to Ecuador from 1951 to 1953. Before becoming the Special Advisor on Antarctica, Ambassador Daniels also served as the chairman of the InterAmerican Coffee Board, director of American Republic Affairs in the U.S. State Department, and Ambassador to the Council of the Organization of American States.

From the point of view of many, Ambassador Daniels was the chief architect of the Antarctic Treaty. When Secretary of State John Foster Dulles recalled Ambassador Daniels from retirement and

appointed him Special Advisor on Antarctica, Daniels knew little about Antarctica. He was, however, one of the State Department's leading experts in Latin American affairs and was familiar with the disputes that existed among Chile, Argentina, and Great Britain, three of the countries that assert antarctic claims. The United States began reviewing its antarctic policy in the fall of 1957. By May 1958, the United States government had sent notes to the 11 other countries participating in Antarctic programs in the International Geophysical Year. The note proposed that these countries, join together and develop a treaty. The preparatory talks for the Treaty began in June 1958. For more than 1 year, Daniels carefully guided these talks that led to the signing of the final draft of the treaty in December 1959.

In recognition of his contributions to the Antarctic Treaty, the U.S. Committee on Antarctic Names honored Ambassador Daniels by naming a mountain range after him. The Daniels Range (71°15'S 160°E) is the principal mountain range in the Usarp Mountains and is 50 miles long and 10 miles wide.

John T. Crowell

John T. Crowell, Special Projects Officer for the U.S. Antarctic Research Program from 1960 to 1969, died on 25 April 1986 at his home on Kimball's Island, Isle au Haut, Maine.

Mr. Crowell's polar career began in the Arctic in 1925 when he became an associate of Donald B. MacMillan, who led a 1925 U.S. expedition to Etah, Greenland; Richard E. Byrd commanded the Navy Flying Unit attached to this expedition. During the next decade, he served as master for the schooners *Sachem* (1926), *Radio* (1927), *Gertrude Thebaud* (1937), and *Bowdoin* (various years) on expeditions to Greenland, Iceland, Baffin Island, and Labrador. While in the U.S. Army, Crowell was in charge (1940-1941) of the installation and first wintering group at the Frobisher Bay base on Baffin Island. During World War II, he planned and operated ferrying bases and weather stations in Canada and Greenland as part of the Army-Air Force arctic air route to Europe. After retiring from the Army, he returned to the Arctic in 1951 to take charge of the U.S. weather station at Thule, Greenland, until 1953 and was also an arctic specialist and advisor to the U.S. Air Force Northeast Air Command. During this time he also assisted in the installation of Distant Early Warning stations in arctic Canada, HIRAN stations in Greenland, emergency air strips in north Greenland, and Fletcher's Ice Island (T-3) in the Arctic Ocean.

In 1960 he joined the staff of the National Science Foundation's Division of Environmental Sciences, where he was

instrumental in developing a two-research-ship fleet for the U.S. Antarctic Research Program. He planned and monitored the conversion of USNS *Eltanin* from a cargo ship to a floating scientific station and was responsible for the design, construction, and commissioning of the research ship *Hero*. While with NSF, Mr. Crowell also supervised multiple contracts for feasibility studies of a manmade Arctic Basin drifting station, led reconnaissance parties to the Antarctic Peninsula, and developed with marine scientists and polar logisticians the Palmer Station/research ship operation still used by the U.S. antarctic program.

Merle Dawson

Colonel Merle "Skip" Dawson, former project manager in the NSF Office of Polar Programs, died of respiratory failure on 14 February 1986. The 76-year-old retired Army Colonel also served in Antarctica during Deep Freeze II (1956-1957).

Before his antarctic service, Dawson served in the U.S. Army from 1943 to 1964. He served in Europe and Asia during World War II and later in the Korean War. Among his assignments were command of Operation Swamp Fox in the Panamanian jungle, participation in the construction and resupply of the Distant Early Warning stations across North America (1952-1953), and instructor at the Army Transportation School at Fort Eustis. During his military career, he received 44 decorations from the U.S. Army and Navy.

In 1956 he was called out of retirement to help establish a safe route from Little America V on the Ross Ice Shelf to Byrd Station in West Antarctica. During a reconnaissance of the route the previous austral summer, Navy personnel had discovered that the more-than-600-mile route was filled with crevasses. In fact, a tractor had fallen into a crevasse, and the driver was killed. Dawson's responsibility was to lay out a trail that would be safe for the tractor trains that would bring supplies to Byrd Station. With the assistance of members of the Army Transport Corps from Greenland, Dawson began the task on 7 November 1956 and completed the trail on 16 December 1956. Through his efforts, the Navy was able to complete Byrd Station for use during the International Geophysical Year.

Dawson joined the staff of the National Science Foundation's Office of Polar Programs in 1965 and was project manager for ship operations until he retired in 1970.

Foundation awards of funds for antarctic projects, 1 July to 30 September 1986

Following is a list of National Science Foundation antarctic awards made from 1 July to 30 September 1986. Each item contains the name of the principal investigator or project manager, his or her institution, a shortened title of the project, the award number, and the amount awarded. If an investigator received a joint award from more than one Foundation program, the antarctic program funds are listed first, and the total amount of the award is listed in parentheses. Award numbers for awards initiated by the Division of Polar Programs contain the prefix DPP, and those initiated by the Division of Ocean Sciences contain the prefix OCE.

Biology and medicine

O'Brian, John T. National Navy Medical Center, Washington, D.C. Thyroid hormone kinetics in cold-exposed man. DPP 85-19514. Logistics support only.

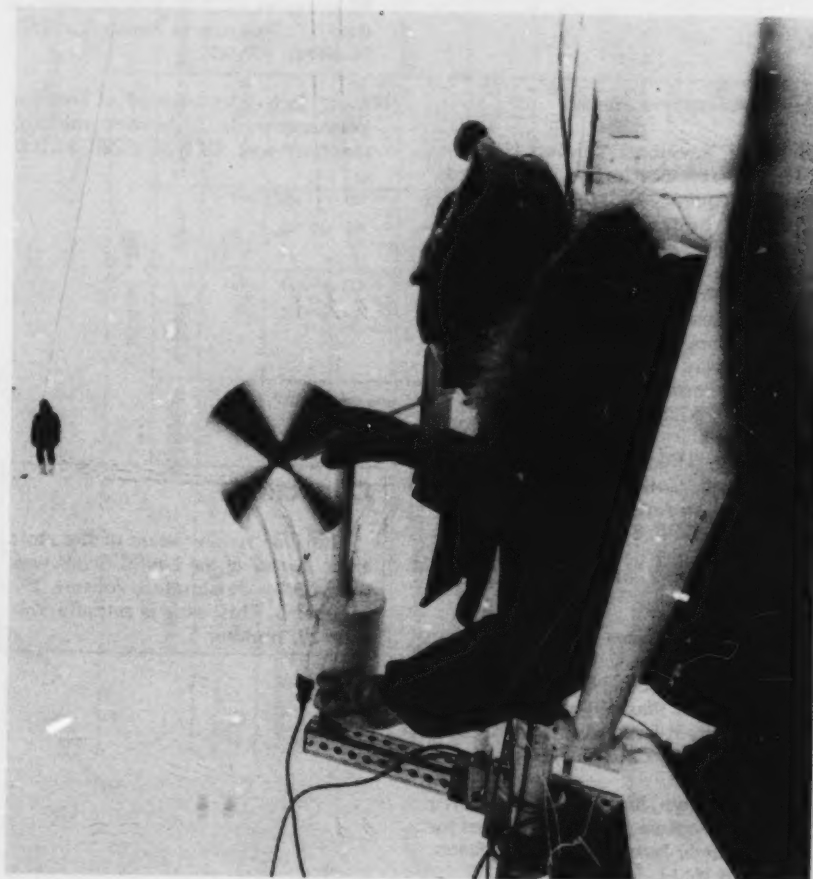
Sullivan, Cornelius W. University of Southern California, Los Angeles,

California. Antarctic marine ecosystem research at the ice-edge zone. AMERIEZ: Sea ice microbial dynamics. DPP 84-44783. \$102,932.

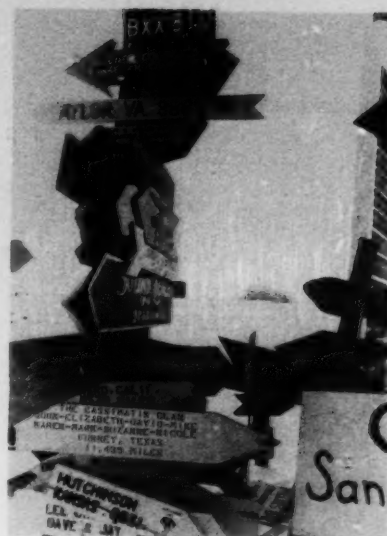
Trivelpiece, Wayne Z. Point Reyes Bird Observatory, Stinson Beach, California. Pygoscelid penguin population studies. DPP 83-14667. \$85,384.

An atmospheric researcher adjusts instruments on the 27-meter meteorologic tower at Amundsen-Scott South Pole.

NSF photo by Ann Hawthorne.



December 1986



NSF photo by Ann Hawthorne.

A reminder of how far away home is from the South Pole, these signposts stand near the ceremonial South Pole. Each season station personnel add new markers.

Earth sciences

Boyce, Joseph. Universities Space Research Association, Houston, Texas. Antarctic meteorite working group. DPP 84-12353. \$40,403.

Dalziel, Ian W. University of Texas, Austin, Texas. Tectonic development of West Antarctica and its relation to East Antarctica. DPP 86-43404. \$100,000.

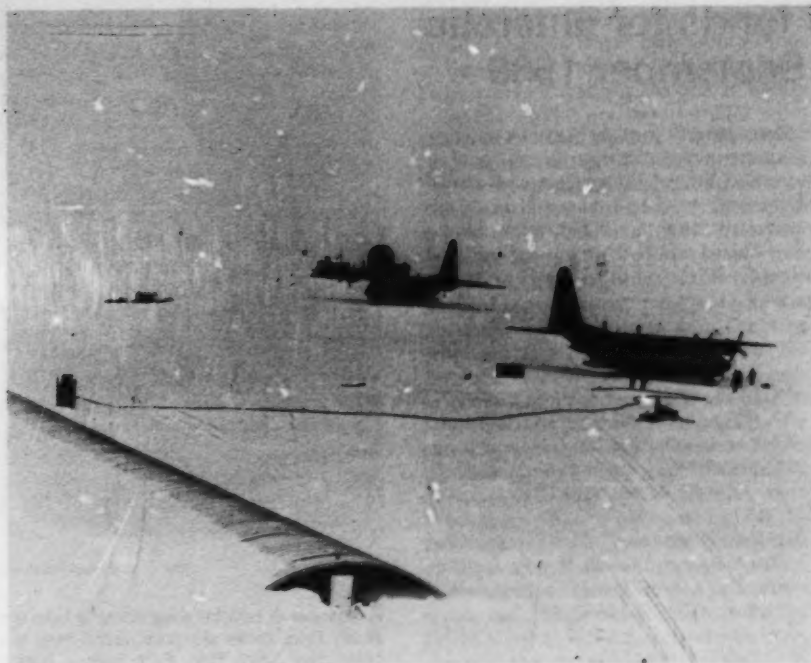
Dalziel, Ian W. University of Texas, Austin, Texas. Kinematic evolution of the Scotia Ridge and southernmost South America: A study of orogenic processes at convergent plate margins. DPP 86-43441. \$188,715.

Hammer, William R. Wayne State University, Detroit, Michigan. Triassic vertebrates from the Beardmore Glacier area. DPP 84-18428. \$38,201.

Glaciology

Bindschadler, Robert A. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland. DPP 85-14543. \$84,150.

Kamb, Barclay. California Institute of Technology, Pasadena, California. Flow mechanism of ice Stream B, West Antarctica. DPP 85-19083. \$228,015.



NSF photo by Ann Hawthorne.

Ski-equipped Lockheed C-130 (LC-130) airplanes wait near the station skiway. These airplanes are essential for maintaining South Pole Station because they transport all personnel, supplies, and fuel from the coast.

Meteorology

Henry, Robert F. State University of New York, Albany, New York. The electrode layer at the South Pole. DPP 85-18001. \$149,470.

Scribner, Orville E. National Oceanic and Atmospheric Administration, Washington, D.C. Argos data collection and location system. OCE 86-43511. \$13,300. (\$56,100).

Ocean sciences

Biggs, Douglas C. Texas A&M University, College Station, Texas. Upper ocean particulate fluxes in the Weddell Sea. DPP 86-02762. \$9,987.

Foster, Theodore D. University of California, Santa Cruz, California. Antarctic bottom water formation. DPP 85-21083. \$56,516.

Weiss, Ray F. Scripps Institution of Oceanography, San Diego, California. Wintertime chlorofluoromethane and surface-water trace-gas measurements in the Weddell Gyre. DPP 85-05631. \$203,082.

Upper atmosphere studies

Grenwald, Raymond A. Johns Hopkins University, Baltimore, Maryland. High-frequency radar studies of conjugate behavior in the polar ionosphere. DPP 86-02975. \$195,126.

Radke, Lawrence F. University of Washington, Seattle, Washington. Airplane maintenance of the data acquisition and display system for the National Science Foundation's LC-130R. DPP 85-07730. \$22,151.

Rosenberg, Theodore J. University of Maryland, College Park, Maryland. Riometry in Antarctica and conjugate regions. DPP 86-10061. \$149,231. (\$173,705).

Support and services

Abbott, Sherburne B. National Academy of Sciences, Washington, D.C. Support for the Polar Research Board. DPP 82-07098. \$80,424. (\$208,274).

Nelson, Marilyn. Blue Pencil Group Inc., Reston, Virginia. Editorial services for the *Antarctic Journal of the United States*. DPP 86-16512. \$17,841.

Starr, Lowell E. U.S. Geological Survey, Reston, Virginia. Surveying and mapping. DPP 85-12516. \$150,000.

Barbee, William D. University of Washington, Seattle, Washington. Support for the University-National Oceanographic Laboratory System (UNOLS) Office. DPP 85-00868. \$3,000. (\$25,330).

Moller, Donald A. Woods Holes Oceanographic Institute, Woods Hole, Massachusetts. Shipboard scientific support equipment—Oceanographic wire rope. OCE 86-17324. \$31,550. (\$151,550).

Wirth, David. Scripps Institution of Oceanography, San Diego, California. Shipboard technician support. OCE 83-16603. \$9,494.

Becker, Robert A. ITT/Antarctic Services, Inc., Paramus, New Jersey. Specialized support of the Antarctic Program. DPP 80-03801. \$5,697,985.

Kuivinan, Karl C. University of Nebraska, Lincoln, Nebraska. Logistics support for polar ice core drilling. DPP 83-18538. \$5,464. (\$396,174).

Srite, David A. Department of Defense, Washington, D.C. Logistic support for the U.S. Program in Antarctica. DPP 76-10886. \$37,000.

Wilson, Jack. Department of Interior, Washington, D.C. Aviation management services. DPP 84-15220. \$1,000.

Correction

The 1985 review issue of the *Antarctic Journal of the United States* was incorrectly designated Volume 19, number 5. This issue is actually Volume 20, number 5.



Weather at U.S. stations

Feature	August 1986				September 1986				October 1986			
	McMurdo	Palmer	Siple	South Pole	McMurdo*	Palmer	Siple	South Pole	McMurdo	Palmer	Siple	South Pole
Average temperature (°C)	-29.3	-9.1	-28.7	-58.4		-9.0	-26.3	-64.1	-17.9	-2.8	-19.9	-53.5
Temperature maximum (°C) (date)	-16.6 (17)	2.2 (22)	-9.2 (23)	-41.3 (17)		6.1 (22)	-4.2 (16)	-49.1 (7)	-7.0 (25)	6.0 (11)	-2.0 (17)	-38.9 (13)
Temperature minimum (°C) (date)	-43.4 (6)	-24.0 (26)	-49.5 (11)	-74.2 (2)		-23.2 (6)	-38.3 (6)	-79.2 (25)	-36.8 (1)	-17.1 (4)	-31.8 (19)	-69.7 (4)
Average station pressure (mb)	985.4	982.4	855.3	673.7		985.3	847.8	665.4	975.9	989.8	855.3	673.5
Pressure maximum (mb) (date)	1002.0 (19)	1005.0 (15)	868.9 (15)	694.0 (18)		1006.0 (1)	866.9 (15)	679.7 (1)	988.6 (18)	1011.5 (29)	870.5 (29)	691.2 (15)
Pressure minimum (mb) (date)	952.8 (8)	956.0 (12)	836.8 (8)	658.9 (7)		961.3 (10)	835.5 (4)	648.0 (22)	959.4 (29)	969.5 (25)	837.0 (31)	663.9 (31)
Snowfall (mm)	48.3	0.4	---	TRACE		0.3	---	TRACE	10.7	15.9	---	TRACE
Prevailing wind direction	030°	325°	219°	030°		345°	204°	090°	110°	030°	191°	090°
Average wind (m/sec)	7.8	8.8	5.8	5.9		9.7	4.5	4.3	6.4	8.6	6.4	4.6
Fastest wind (m/sec) (date)	30.4 (9) 150°	36.0 (30) 040°	17.0 (1) 270°	20.2 (13) 360°		36.0 (2) 010°	18.5 (20) 270°	16.5 (9) 020°	32.6 (3) 150°	28.8 (31) 360°	20.6 (30) 310°	14.4 (13/14) 010°
Average sky cover	2.9	9/10	5/10	0.5		9/10	5/10	0.4	6.8	8/10	7/10	0.5
Number clear days	20.0	1.9	14.0	12.9		2.6	7.3	19.2	3.0	3.7	4.3	13.9
Number partly cloudy days	9.0	2.3	3.3	5.4		5.9	6.8	4.9	18.0	3.7	2.5	2.5
Number cloudy days	2.0	26.8	8.8	12.7		21.5	11.3	5.9	10.0	23.6	15.8	13.6
Number days with visibility less than 0.4 km.	1.0	---	5.0	4.7		---	4.8	2.2	0.8	---	8.5	2.0

Prepared from information received by teletype from the stations. Locations: McMurdo 77°51'S 166°40'E, Palmer 64°46'S 64°3'W, Siple 75°55'S 63°55'W, Amundsen-Scott South Pole 90°S. Elevations: McMurdo sea level, Palmer sea level, Siple 1054 meters, Amundsen-Scott South Pole 2835 meters. For prior data and daily logs, contact National Climate Center, Asheville, North Carolina 28901.

* September 1986 climate data for McMurdo Station is not available.

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